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(*continued inside back cover*)

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ANNALE VAN DIE SUID-AFRIKAANSE MUSEUM

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PROCEEDINGS
OF THE
SOUTHERN AFRICAN SOCIETY
FOR
QUATERNARY RESEARCH

Conference on recent progress in later Cenozoic Studies
in southern Africa, 31 May — 3 June 1975

PREFACE

The most recent biennial conference of the Southern African Society for Quaternary Research (SASQUA) was held at the South African Museum in Cape Town from 31 May to 3 June 1975. This volume contains a series of papers presented at the conference which itself was part of the one hundred and fiftieth anniversary celebrations of the South African Museum. SASQUA is grateful to the Board of Trustees, the Director, Dr T. H. Barry, and to the staff of the museum for acting as hosts to the conference and for making the more than eighty delegates most welcome. A further acknowledgement is due for the invitation to publish the proceedings in the museum *Annals*. A Cenozoic Study Group was established at the museum some years ago to promote Palaeontological, Geological and Archaeological research in the Quaternary and later Tertiary in the southern Cape and a number of papers in this volume reflect the direct or indirect stimulus given to Quaternary research by the museum.

The conference was held over four days from a Saturday to a Tuesday. To cope with the unpredictable Cape winter weather, meetings and excursions were held on alternate days on the advice of the consulting geographer on the organizing committee, Professor Barnard, but happily there was fine weather throughout. The Saturday morning sessions were divided between Geology A (sea-levels), chaired by Dr O. Davies with a lead address given by Mr A. J. Tankard, and Geology B (terrestrial) chaired by Professor G. Söhnge with the lead address given by Professor A. O. Fuller. The Saturday afternoon session was devoted to dating problems in the Cenozoic, the chairman for the session being Dr J. C. Vogel and an address was given by Professor A. Brock. The Sunday was given over to a field trip to the Walker Bay coast near Gansbaai with visits to the Die Kelders and Byeneskrans archaeological excavations, led by Mr F. R. Schweitzer.

On the Monday, Palaeoecology was the subject-matter of the first session with the chairman Dr C. K. Brain, and the lead address given by Professor E. M. van Zinderen Bakker. The second morning session was devoted to Anthropology *sensu lato* with Dr H. J. Deacon as chairman and the lead address given by Professor R. J. Mason. In the final meeting of the day, keynote addresses were given by the distinguished guests of the Society, Professor H. de Lumley of the University of Provence and Professor W. W. Bishop of the University of London. The fourth and final day was spent visiting the palaeontological site of Langebaanweg and geological exposures in the Saldanha Bay area, the excursion being led by Dr Q. B. Hendey and Mr A. J. Tankard.

Thanks are due to the chairman of the sessions for guiding the discussions which followed on the lead addresses, and on the papers that were allocated to their sessions. As the papers were circulated before the meeting, individual papers were not formally read and the chairman's role in ensuring adequate discussion was an important one. Thanks are also due to the leaders of the excursions which allowed for useful informal discussions and a glimpse of on-going research. The conference itself was organized by a local committee that included Professor W. S. Barnard, Dr H. J. Deacon, Dr Q. B. Hendey, Mrs D. M. Leakey, Mr J. Rogers, Mr F. R. Schweitzer and Dr W. G. Siesser. As secretary of the committee and as assistant editor of the proceedings, much of the success of the conference is due to the untiring efficiency and hard work of Mrs Leakey.

This volume is a fair reflection of the substance of the conference and the papers are grouped in the same order as in the conference programme. Contributions in French have been translated into English by Mrs Leakey for publication for which further acknowledgement is gratefully made. Mrs Ione Rudner a delegate and member of the South African Museum staff and editor of the *Annals*, has given invaluable guidance in editorial matters and has effectively seen the papers to press. All delegates to the meeting will agree that if we are indeed the product of the union between *Paranthropus* and *Australopithecus* as was so well argued by Bill Bishop in his best alto to the acclaim of all present then much good came of that union. SASQUA, as a body devoted to the study of the setting and results of this lowly hominid love-match, has an important contribution to make to our knowledge. These proceedings, the third in the history of the Society, are part of this contribution.

H. J. Deacon

University of Stellenbosch

Honorary Editor of Proceedings

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SECTION 1

GEOLOGY A. SEA-LEVELS

CENOZOIC SEA-LEVEL CHANGES: A DISCUSSION

By

Anthony J. Tankard

South African Museum, Cape Town

(With 2 figures)

ABSTRACT

Recent studies of the history of existing ice sheets, sea-floor spreading, deep-sea cores, isotopic composition changes of ocean waters and isostatic responses to varying loads, are reviewed with regard to their bearing on sea-level changes. Only sea-levels of the past 125 000 years are discussed in any detail.

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INTRODUCTION

Palaeogeographic studies show that all the major coastlands of the world have been subjected to alternating periods of submergence and emergence. Old high-level shorelines and submerged terraces show that sea-level has oscillated considerably in the past. In 1842 Maclaren introduced his concept of glacial control to explain an oscillating sea-level during the Quaternary Period. According to 'classical' theory a series of stepped marine terraces are produced by a sea-level which fluctuates in response to waxing and waning of continental ice sheets, and each successive high sea-level was lower than the previous (Trowbridge 1954). To cite an example, transgression complexes on the Namaqualand coast have been recognized at 75–90 m, 45–50 m, 29–34 m, 17–21 m, 7–8 m, 5 m, and 2 m, and these range in age from basal Pleistocene to Recent (Carrington & Kensley 1969).

The assumption that the order of decreasing altitude of the elevated shorelines corresponds with a decreasing age was confirmed by Flemming (1968). He showed that an oscillating sea-level will not necessarily obliterate previous erosion features, but that there is a general absence of random positions of high-level shorelines. A descending chronological order implies that the shorelines are the result of either a series of sea-level oscillations of decreasing

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magnitude, or the result of a series of oscillations of approximately equal magnitude superimposed on an overall regression (Flemming 1968). The fact that the Pleistocene glaciations were of nearly equal magnitude (Flint 1971) would support the second option.

There have been several attempts in recent years to synthesize data on eustatic sea-level changes (e.g. Fairbridge 1961; Guilcher 1969; Hey 1971).

As Hey points out, any attempt to interpret the field-evidence becomes an exercise in correlation. South African literature on the subject of high-level shorelines is generally of doubtful quality as there are no means of dating these shorelines and reliance is placed on long-distance correlation with the 'firmly established' Moroccan and other sequences. The horizontality of a shoreline over considerable distances does not disprove the possibility of tectonism (Cotton 1963; Bloom 1967), while the southern African coastlands, in particular, have a poor record of Cenozoic stability. Not only can we not separate the climatic from the tectonic influences on sea-level, but it is also common practice to ascribe high-level shorelines to named Late Cenozoic stages on the mistaken assumption that the northern hemisphere climatic history is well known and the stages adequately defined.

The recent publication of new evidence bearing on eustatic sea-level studies makes a discussion opportune. The purpose of this paper will be to discuss some of the more important factors and data dealing with eustatic sea-level changes. Current research on the existing ice sheets, deep-sea cores and oxygen isotope studies, sea floor spreading, and the bearing these have on eustatic sea-level studies will be discussed. Particular attention will be paid to glacio-eustatic sea-level oscillations of the last 125 ka (125 000 years) because only for that period are there adequate and reliable data, and the effect of ocean floor spreading would be expected to be minimal. In this paper the term 'eustatic' will apply to changes of sea-level relative to a fixed datum, say the centre of the earth, and which are synchronous over the whole globe.

GLACIO-EUSTATIC CONTROL OF SEA-LEVEL

If high-level shorelines, higher than 30 m above present mean sea-level (a.s.l.) for instance, were of glacio-eustatic origin it would be implied that the existing continental ice sheets had melted and again built up several times in the Quaternary. The history of these ice sheets show that this has not happened.

Although there is little evidence for the existence of large continental ice sheets prior to the Middle Miocene, some evidence suggests the presence of calving glaciers in the Eocene (Denton *et al.* 1971). The first major cooling is closely associated with the Eocene–Oligocene boundary (Devereux 1967; Kennett *et al.* 1974), and although Oligocene temperatures on Antarctica were close to freezing there was no development of an extensive ice sheet (Shackleton & Kennett 1974). But Margolis & Kennett (1970) document evidence of some glaciation during the Oligocene. Evidence of glaciation prior to 22 m.y. B.P. is provided by radiometrically dated basalts overlying a Tertiary tillite (Craddock *et al.* 1964; Rutford *et al.* 1968). It seems highly likely that the glaciers were only mountain or valley glaciers. A rich and varied fossil flora suggests not only that extensive ice sheets had not developed in the Lower Tertiary, but also that until at least the Early Miocene the climate was generally temperate (Denton *et al.* 1971).

Analysis of cores from the floor of the Ross Sea (DSDP leg 28) suggests extensive glaciation on eastern Antarctica at least by the Early Miocene (Hayes *et al.* 1973). Shackleton & Kennett (1974) (DSDP leg 29) have found that the Antarctic continental ice sheet developed to present thickness between the early Middle Miocene and early Late Miocene, and that by the Late Miocene–Early Pliocene the Antarctic ice sheet was much more extensive than at present. This development was accompanied by a major regression. The maximum of ice accumulation 4 to 5 m.y. ago was followed by an abrupt melting and ice retreat to the present position (Hayes *et al.* 1973). Subsequent fluctuations in the Antarctic ice cover have been minor. Studies of deep-sea cores show that Antarctic glaciation has been continuous for the last 3 to 5 m.y. (Koster 1966; Goodell *et al.* 1968).

It has been suggested by Savin *et al.* (1975) that until the beginning of the Middle Miocene high- and low-latitude temperatures changed in similar fashion. They record a lowering of temperature from the Late Eocene until the Late Oligocene, followed by a rise in temperature through the Early Miocene. Onset of major glaciation and development of the circum-Antarctic oceanic circulation in the Middle Miocene led to a sudden divergence of high- and low-latitude marine temperatures.

On radiolarian evidence Fillon (1973) has shown that for the last 3 m.y. surface water temperatures south of 65°S were never warmer by more than about 3°C than they are today. Mercer (1968*a*) has found that at some time during the Pleistocene Antarctic temperatures could have been 7 to 10°C higher than today, but he notes that the present −10°C January isotherm lies close to the coast. A low amplitude temperature fluctuation could not lead to significant ice melting.

In the northern hemisphere full glacial conditions have prevailed in Alaska since the Late Miocene (Miller 1953; Bandy *et al.* 1969; Denton & Armstrong 1969). In a study of several cores from the Arctic Ocean Clark (1971, 1974) showed that since at least the Early Pliocene the Arctic Ocean has been continuously ice covered and that the present thickness of the ice is a minimum. He found that the Arctic Ocean was ice-free until the Eocene, but that the ice sheet must have formed some time between the Eocene and Pliocene. Shackleton & Kennett (1974) suggest a Late Pliocene development of northern hemisphere glaciation.

Melting of the existing ice sheets (east and west Antarctica, Greenland, and others) would cause sea-level to rise 65 m (Flint 1971). But there is overwhelming evidence that the land-based eastern Antarctic ice sheet was stable throughout the Pleistocene and could have contributed little to sea-level movement. The Antarctic ice sheet possibly underwent periodic surges into the Southern Ocean. but there is little evidence to support this (Denton *et al.* 1971). Data from deep-sea cores argue against surges, but do not eliminate the possibility of smaller surges.

Mercer (1968*b*, 1973) has found that the marine ice sheet in western Antarctica is more vulnerable to climatic change and its melting would have caused a eustatic rise in sea-level of about 5 m. Isotopic studies of the Greenland ice (Dansgaard *et al.* 1969) suggest that only 15 per cent of that ice is residual from the last glacial and preceding interglacial age. This led Emiliani (1969) to suggest that high Late Pleistocene sea-levels resulted from melting of this Greenland ice sheet and that melting would cause a eustatic rise in sea-level of about 10 m. Taking a conservative view, that both the Greenland and western Antarctic ice sheets contributed to Pleistocene eustatic sea-level movement while the large eastern Antarctic ice sheet remained stable, the maximum glacio-eustatic rise of sea-level could not have exceeded 15 m at any stage in the Pleistocene.

These conclusions are broadly supported by oxygen isotope studies of deep-sea cores. Accumulation of the vast isotopically negative Pleistocene ice sheets resulted in a lowering of sea-level. At the same time the oceans became isotopically positive and more saline. The original aim of oxygen isotope studies was to measure palaeotemperature (e.g. Emiliani 1955, 1966). Shackleton & Opdyke (1973) have published a record of ocean isotopic composition changes for the last 800 ka. They note that such a record is of greater stratigraphic value than a record of temperature change.

Based on a rough equivalent of 0,1‰ isotopic deviation to 10 m sea-level change, Shackleton & Opdyke (1973) have drawn a glacio-eustatic sea-level curve for the past 130 ka. The remarkable agreement between positions of sea-level shown on this curve and those measured on Barbados (Broecker *et al.* 1968) and New Guinea (Veeh & Chappell 1970) proves the correctness of the method. It thus becomes possible to use the record of oxygen isotopic composition in core V 28–238 (Shackleton & Opdyke 1973: fig. 9) as a sea-level curve for the past 800 ka. This record shows that sea-level during isotopic substage 5e (+6 m) was the highest in the last 800 ka, and that only twice in this interval did sea-level exceed present sea-level, at about 400 ka and again at about 320 ka.

In conclusion, it must be emphasized that a sea-level curve derived from oxygen isotope measurements gives a reasonably clear record of glacio-eustatic sea-level changes without the complicating effects of tectono-eustasism or isostatic adjustments of the globe to changing loads. The history of the existing ice sheets shows that the glacio-eustatic component could not have caused a sea-level rise much above present sea-level in the Pleistocene. The major Antarctic ice sheet appears to have existed in its present form since the Pliocene. It is unlikely that the history of these ice sheets could account for the major Late Cretaceous and Tertiary (Eocene and Miocene) transgressions.

SEA-FLOOR SPREADING AND TECTONO-EUSTATIC CHANGES

The new theory of global tectonics has transformed numerous branches of geological research, and the field of eustatic sea-level change has not emerged unscathed. By this concept crustal plates grow along the mid-ocean ridges and sink or override each other where they again come into contact. Changes in the rate of accretion at mid-ocean ridges will lead to changes in the depth of the oceans, since elevation or subsidence of sea-floor is a function of ridge activity. The idea that ridge activity may affect sea-level has been postulated by Hallam (1963, 1971), Russell (1968), Menard (1969), Frerichs & Shive (1971), Flemming & Roberts (1973) and Vine (1973). Flemming & Roberts have attempted to correlate eustatic changes with contemporaneous global spreading discontinuities, and can explain the major Late Cretaceous, Eocene and Miocene transgressions in this way. Hallam (1971) and Hays & Pitman (1973) believe that the Late Cretaceous transgression was due to oceanic-floor uplift consequent upon accelerated sea-floor spreading. The Miocene eustatic rise due to spreading rate changes could be of the order of hundreds of metres (Flemming & Roberts 1973). If there had been no ridge activity in the Cenozoic, and allowing for isostatic adjustment, sea-level would today be 350 m lower than in fact it is (Vine 1973).

According to Jacoby (1972) the effect of plate movement is to create an environment of changing density in which continental blocks of constant density will float up or down. For instance, in an environment of greater density caused by cooling of the upper mantle the continental blocks would float upward, causing a regression. Conversely, decreasing density would result in transgression.

Rona (1973) has recorded average rates of sediment accumulation from wells on the continental shelves and slopes. He found maxima of sediment accumulation, corresponding to major transgressions, in the Middle Eocene and Miocene. Each maximum is separated by a minimum which corresponds to regressive phases. Rona equates the transgressions with a volume increase of the mid-ocean ridges resulting from fast-spreading and orogenic quiescence of continents. Regression corresponds to decrease of mid-ocean ridge volume with slower spreading and orogenic activity of the continents.

Increased ridge activity in the Eocene and Miocene would adequately account for marine transgressive complexes of those ages around the southern African coast. Tertiary marine sediments are preserved in depressions in the Precambrian basement south of Lüderitz. Haughton (1963) suggested that most of the fossil fauna was Miocene, and that Eocene deposits were preserved at higher elevations. *In situ* Middle Eocene marine sediments also occur in Mozambique (Du Toit 1954). Along the South African coast the only evidence for an Eocene transgression consists of reworked deposits at Uloa (Frankel 1968) and Birbury (Bourdon & Magnier 1969). Otherwise the major transgressive complex deposits in South Africa are of Miocene age (King 1953; Frankel 1968; Ruddock 1968; Tankard 1975).

These authors also describe Pliocene transgressive complexes. The west coast Pliocene deposits can be attributed entirely to tilting and there is no need to invoke a eustatic sea-level rise. Furthermore, Frankel (1968) disputes that there are Pliocene marine sediments along the Zululand coastal plain.

Hallam (1973) suggests that due to continued subsidence of the ocean floors, sea-level was generally regressive through the Pliocene and Pleistocene following the Miocene peak. A change of elevation of the ocean floors implies a subcrustal transfer of mantle material. Depression of the ocean floors would transfer mantle material towards the continental blocks and would cause them to float upwards. But there would be a transitional zone of flexure where the rising continental block was coupled to the downwarping ocean floor. Mention has already been made of the maximum of ice accumulation 4 to 5 million years ago in the Antarctic which was followed by abrupt melting and ice retreat to the present position. The time lag between this melting and attainment of hydro-isostatic equilibrium could have been marked by a Late Pliocene transgression, albeit minor compared with the Miocene transgression.

PLEISTOCENE HIGH-LEVEL SHORELINES

Assuming a uniform regression from the Miocene eustatic high, +300 m according to Flemming & Roberts (1973), the basal Pleistocene sea surface would have been 50–60 m above present. This general regression, the result of downwarping of the ocean floors, would probably be accompanied by uplift of the continental blocks and continued flexuring of the margins. The increased Late Pliocene melt water suggests a basal Pleistocene sea-level even higher than 50–60 m before hydro-isostatic equilibrium was achieved. But this is all speculation since little is known about the course of events following a Late Pliocene melting of Antarctic ice and since our knowledge of sea-floor spreading is far from complete. Bloom (1971) warns that it 'would be foolhardy to infer anything about glacial-eustatic control of sea level during one of the early Pleistocene glaciations, for instance, in the face of evidence that the ocean basins are widening at rates of up to 16 cm per year . . .'.

To obtain sets of discrete high-level shorelines such as have been described for the South African coast (Carrington & Kensley 1969; Davies 1970–1973, and others) one could speculate that it would be possible to superimpose a glacio-eustatic curve derived from oxygen isotope composition changes in the Pleistocene on a sea-level regressing due to subsidence of the ocean floors. It is doubtful, however, whether this would produce meaningful results. Shackleton & Opdyke (1973) record a sea-level at stage 9 (approximately 560 ka) near present sea-level. To raise this shoreline to +30 m either by uniform rate of uplift of the coastal area, or tectono-eustatic effects, would ensure that the 120 ka shoreline (+6 m) would today be recorded at +15 m. Davies (1970) suggests that the Natal 60 m shoreline is of Cromerian age. The 'Cromerian Complex' probably extends from 350 ka back into the Matuyama Epoch

(Shackleton & Opdyke 1973). Furthermore, Davies (1970, 1973) claims that the 30 m and 60 m beaches contain Acheulian artefacts, but the lower limit of Acheulian time is about 700 ka according to Klein (1974). The oxygen isotopic composition record shows a peak at about that time, stage 19, close to the present sea level. At a uniform rate of uplift to elevate such a shoreline to +60 m, the 120 ka shoreline would be found today at about +16 m. What is believed to be the 120 ka shoreline has been identified in Zululand at +8 m (Hobday 1976), and in the Saldanha area at +6,3 m (Tankard 1976). This type of reasoning suggests that the 30 m, 60 m, and higher shorelines, could be no younger than the Early Pleistocene on a 'stable' coast.

LAST INTERGLACIAL SHORELINES

In the Late Quaternary a more realistic appraisal of sea-level fluctuation is possible because:

1. The effect of sea-floor subsidence due to spreading changes would be minimal.
2. Elevations of the shorelines can be explained by changes in the ice sheets.
3. Adequate data is available. In this discussion the last interglacial will be taken as equivalent to isotope stage 5, a time range 128 to 73 ka (Suggate 1974).

Emiliani (1961), Shackleton (1969), Shackleton & Opdyke (1973), and Emiliani & Shackleton (1974) have analysed deep-sea cores spanning the last 500 to 800 ka. In all of these studies substage 5e of the last interglacial registers a higher palaeotemperature than the maximum post-glacial (stage 1) or any earlier stage. Substage 5e corresponds to a sea-level maximum at 120 ka. Shackleton & Opdyke have derived, from oxygen isotope measurements, a glacio-eustatic sea-level curve for the past 130 ka. The curve shows four maxima which have been compared with estimated sea-levels on Barbados (Broecker *et al.* 1968) and New Guinea (Veeh & Chappell 1970). Only the substage 5e sea-level (Barbados III) at 120 ka is higher than the present sea-level. There are also two other maxima in the last interglacial, both 10 to 20 m lower than present sea-level: BII at 100 ka and BI at 80 ka.

Uranium series dating of corals from shorelines between 1,5 and 9 m above present datum from various parts of the Indian and Pacific Oceans yield dates of the order of 120 ka (Veeh 1966). Undoubtedly the most detailed and most reliable results in recent years have come from Barbados and New Guinea. Both these islands have been uplifted at a uniform rate. On Barbados Broecker *et al.* (1968) have recognized three last interglacial sea levels at elevations +6 m (BIII), −13 m (BII), and −13 m (BI), which have been dated at 122 ka, 103 ka, 82 ka respectively. A similar sea-level curve based on a series of transgressive-regressive cycles identified from a series of coral reefs on New Guinea independently confirms each high sea-level stand on Barbados (Veeh & Chappell

1970). The evidence from Barbados and New Guinea for two −13 m peaks at 80 ka and 100 ka explains why these levels are seldom recognized from continental coastlands.

On Mallorca Butzer & Cuerda (1962) recorded Tyrrhenian II shorelines at 12,5 m and 7,2 m with a 120 ka age, and a Tyrrhenian III shoreline at 2,2 m with an age of 80 ka. Molluscs from cemented terrace deposits from the western Mediterranean and Moroccan coasts are suggestive of sea-level stillstands in those areas at 120 ka and 80 ka.

The shoreline between 2 and 7 m above present sea-level which is widely recognized in places remote from plate boundaries, and which formed at 120–130 ka, is becoming commonly used as a Late Pleistocene sea-level datum (Chappell 1974). If this shoreline is situated higher than +7 m it would infer tectonic uplift (Chappell 1974). Hobday (1976) has recognized three last interglacial shorelines from the St. Lucia area of Zululand: 8 m, 3,4–5,3 m, and 4,5 m. Three last interglacial shorelines have also been recognized in the Saldanha area of the south-western Cape: 6,3 m, 2–3,5 m, and 0 m (Tankard 1976). In both of these cases the highest beaches would agree with the so-called Late Pleistocene datum and should therefore be unaffected by displacements such as hydroisostatic adjustments. It therefore becomes difficult to reconcile the two low levels with the BII and BI levels, although they agree well with the Mallorca series described by Butzer & Cuerda (1962). Perhaps all three of these last interglacial shorelines from South Africa should be equated with BIII.

SEA-LEVELS OF THE LAST GLACIAL AGE

Interstadial sea-level

In North America Milliman & Emery (1968) cited 15 radiocarbon dates on carbonate samples to predict an interstadial sea-level as high as the present at 35 ka. Numerous other authors have followed them (see Thom 1973 for a full discussion). However, a considerable amount of evidence has been published which shows that such a high interstadial sea-level is unlikely. This subject has been treated in great detail by Thom (1973), and only a few comments will be given here.

A glacio-eustatic sea-level curve derived from oxygen isotope measurements on deep-sea core V28–238 shows sea-level to have been considerably lower than the present level during the interstadial (Shackleton & Opdyke 1973: fig. 7). This curve agrees with the New Guinea data (Veeh & Chappell 1970) although it was derived from independent lines of reasoning, and must therefore be basically correct. The NG III data shows a corrected shoreline at −20 m at 35 ka. According to Broecker & Van Donk (1970) sea-level could not have been closer than 18 m from present sea-level between 35 and 45 ka.

Glacio-climatic evidence proves the impossibility of sea-level being close to present sea-level during the interstadial (Mörner 1971). The last glaciation did not possess a warm interval of comparable intensity or duration to that which exists at present, or prior to 60 ka and oxygen isotope measurements on Greenland ice cores failed to show values equivalent to an interglacial or to present conditions (Thom 1973). Continental ice fronts during the interstadial lay in south-western Sweden and at the line of the Great Lakes in North America (Fairbridge 1971).

Fairbridge has recorded discussions at the eighth INQUA congress. It was stated that a high interstadial sea-level to +3 to 5 m relies on dated carbonate material. Studies carried out by the Columbia University radiocarbon laboratory show that all shell dates older than 20 ka are subject to miniscule contamination which gives meaningless 'dates' and which should be reported as 'greater than . . .'. Fairbridge concludes that any 'postulated glacio-eustatic level for this epoch anywhere near present sea-level is absolutely out of the question'.

Figure 1 is a South African time-depth plot of sea-level over the last 47 ka based on 20 radiocarbon dates derived from wood, peat, or carbonate samples from below sea-level, or very deeply buried, so that the chance of contamination by atmospheric CO_2 is thus minimized. These samples are all identified with shallow nearshore environments, but are unfortunately representative of widely scattered localities from west of the Cape Peninsula to Zululand. A line is drawn through the points to draw the eye, and should be regarded only as a crude approximation to sea-level history over the past 47 ka.

The curve suggests that between 47 ka and 25 ka there was a sea-level maximum at approximately —20 m. A lengthy stillstand at this level would be expected to leave topographic evidence. Rocky Bank, south of the Cape Peninsula, was most likely formed by a sea-level at this elevation (Flemming 1976) as was a prominent submerged cliff at —20 m along parts of the west coast of the Cape Province and South West Africa (Wright 1964; Murray *et al.* 1970).

Glacial maximum sea-level

Evidence for low sea-levels between 15 and 20 ka, during the glacial maximum, have recently been discussed by Chappell (1974). Dated shallow marine deposits vary in depth from —65 m to —150 m. The most consistent results are from the Texas continental shelf. There a sea-level lowering of 130 m at 15 ka compares with a lowering of 90 m at 17 ka for the eastern continental shelf and 130–170 m for Australia (Chappell 1974). Using Walcott's (1972) corrections for elastic warping, Chappell calculates a minimum sea-level of —135 m. As he points out this agrees very favourably with Flint's (1971) estimate of —130 m calculated from ice volumes. Oxygen isotope results suggest a lowering to —120 m (Shackleton & Opdyke 1973).

The South African time-depth curve (Fig. 1) suggests a rapid fall of sea-level with advance of the final Würm glaciation and that a minimum sea-level of —130 m was reached at 17–18 ka.

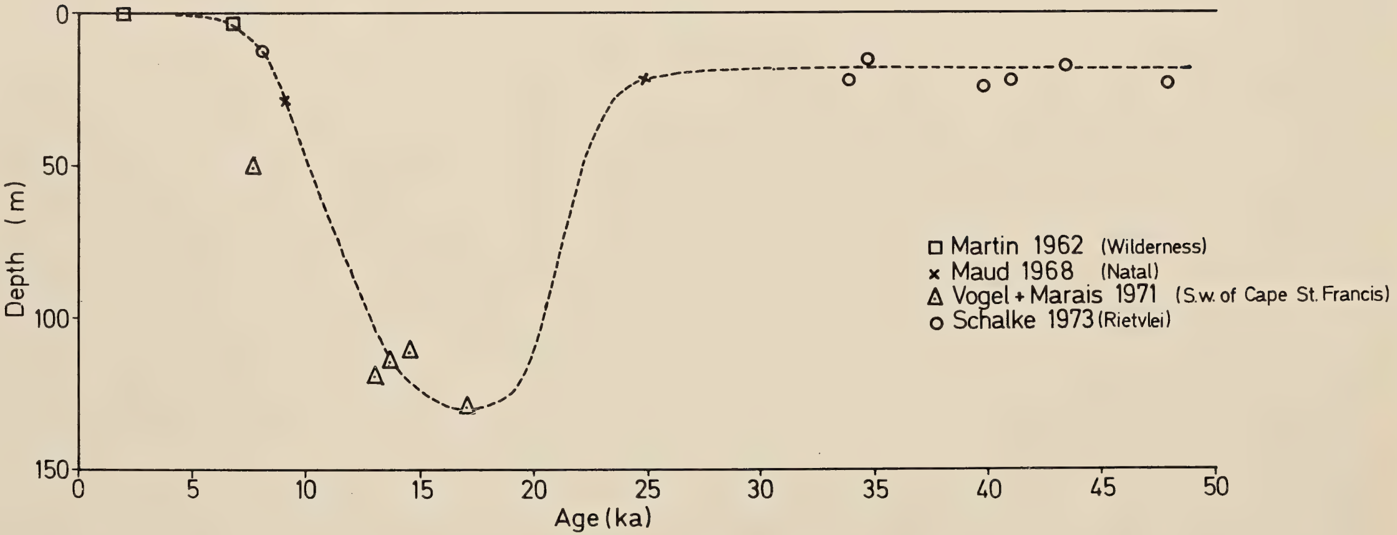

Fig. 1. Relative sea-level curve for last 47 ka for South Africa.

POST-GLACIAL SEA-LEVEL

In this section the author proposes to discuss the changes in sea-level during the Holocene, and mainly the past 6 000 years. Widely divergent opinions about the course of sea-level rise persist because little account is taken of the isostatic responses of the earth crust to changing ice and water loads. The hydro-isostatic effects will vary with location according to continental shelf geometry and structure of the underlying mantle. A prerequisite in any Holocene shoreline study is the accurate identification of the 125 ka datum (+5 ± 3 m) in that area (Thom & Chappell 1975).

Following the maximum glacial advance, the rate of retreat of the ice was nearly constant, and the present extent was reached at about 6,5 ka (Bloom 1971: fig. 4). Bloom's curve is reproduced in Figure 2 along with several esti-

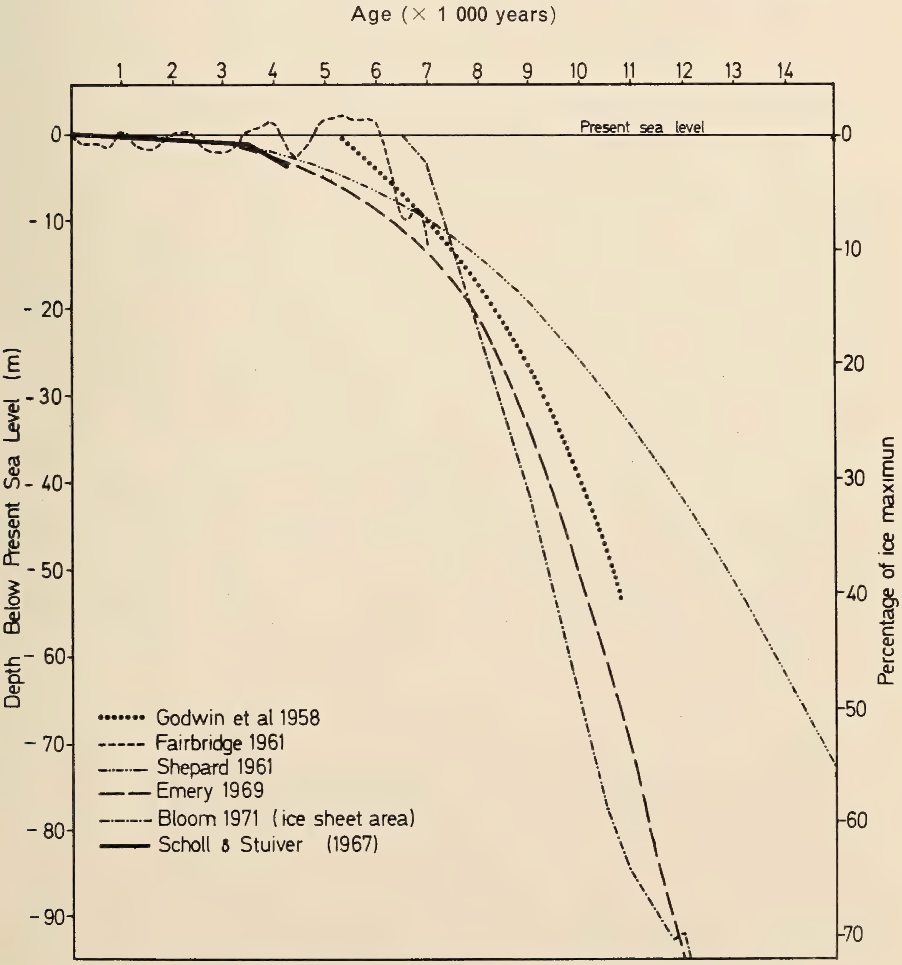

Fig. 2. Holocene sea-level rise, showing different concepts.

mates of sea-level rise. Generally there appears to have been a rapid rise of sea-level, but the rate has decreased with diminishing age.

Ignoring the isostatic responses of the crust to changing loads, there is a threefold division of opinion on the course of sea-level rise (discussed in detail by Jelgersma 1971). These are (Fig. 2):

1. *The oscillating sea-level concept* (Fairbridge 1961). Fairbridge finds evidence, mainly from Australia, for postglacial sea-levels at 3–5 m a.s.l. (5 ka), 1,5–2 m a.s.l. (3,7 ka), and 0,6–1,0 m a.s.l. (2,3 ka).

2. The *steady sea-level concept* (Godwin *et al.* 1958) suggests sea-level rose rapidly until reaching the present position at 5,5 ka. Sea-level supposedly remained constant since.

3. Finally, there is the *continuously rising sea-level concept* (Shepard 1961, 1963). According to this concept the postglacial rise of sea-level has been asymptotic and for the last 5 ka sea-level has been rising continuously. Shepard's data indicates a rapid rise from 17 to 6 ka when sea-level stood at −6 m. This was followed by a slow rise to −1,8 m between 3,5 and 2 ka.

A very detailed work is that of Scholl & Stuiver (1967) on the stable Everglades coast of southern Florida. They see a rapid rise of sea-level to −1 m at 3 ka, since when sea-level has risen slowly.

Scholl & Stuiver could find no evidence in the Florida region in support of high Holocene sea-levels as postulated by Fairbridge (1961). They pointed out that a slight rise in sea-level in the Everglades region would have left a very substantial record. Furthermore, they question the significance of radiocarbon dates from the Everglades that were used by Fairbridge. Shepard (1963, 1964), Russell (1963), Shepard & Curray (1965), Hails (1965) and Thom *et al.* (1969) are rather sceptical of the significance of Australian radiocarbon dates used by Fairbridge (1961), Gill (1961) and Ward (1965). Thom *et al.* (1969) have found no morphological or stratigraphical evidence for sea-levels higher than the present in eastern Australia, which supposedly has a stable coastline, between 2 985 and 9 000 B.P. Although there was a post-glacial climatic optimum between 4 000 and 2 000 B.C., Lamb (1966) is doubtful that there could have been a corresponding rise in sea-level because continental ice-sheets were still too extensive. The Brenner Pass, for example, may not have been open before 1 800 B.C.

Recent studies (e.g. Bloom 1967, 1971; Walcott 1972; Chappell 1974) demonstrate that the continental margins are not necessarily stationary, but that changing ice and water loads induce displacement of the earth's surface which may take the form of rapid elastic adjustments and slow viscous mantle flow (Chappell 1974). The course of sea-level rise relative to the continental margins varies with location, and is affected by shelf geometry and physical structure of the underlying mantle (Thom & Chappell 1975). Bloom (1971) argues that, because the shelf off the Florida Everglades is very shallow, downwarping due to hydro-isostatic compensation would be minimal, and that the curve drawn by Scholl & Stuiver (1967) would be a realistic glacio-eustatic curve. Walcott's (1972, fig. 1) map of elastic warping strengthens this argument since the Florida Everglades lie on his 100 per cent contour, i.e. no vertical displacement due to elastic deformation of the earth. Florida is also remote from plate boundaries. According to Walcott (1972) no substantial change of sea-level is necessary to explain sea-level of the last 6 000 years.

Deglaciation and the consequent sea-level rise following the —130 m low at about 17 ka involved on average depression of the ocean floors of about 8 m, and an average upward movement of the continents of about 16 m (area of the continents half that of the oceans) in the last 7 ka (Chappell 1974). Furthermore, there would be a zone of flexuring where ocean basins and continents meet. These effects differ with locality. If there is a vertical movement of the continent and flexuring of their margins relative to the ocean floors, then the most desirable place to measure glacio-eustatic change would be on mid-oceanic islands which follow the movement of the ocean floors (the 'dip-stick' effect).

Data from eastern Australia and Christchurch, New Zealand, both stable areas, allowed Chappell (1974) to draw a continental coast sea-level curve. This curve shows present sea-level to have been attained by 6 000 B.P. and to have remained static relative to the continent since then. Recalculation of the sea-level data from the continental curve to give movement of sea-level relative to ocean basins shows that sea-level has been rising continuously throughout that period, and that the course of sea-level rise relative to the ocean basins agrees with the results from midoceanic islands and the Florida Everglades.

The South African sea-level curve (Fig. 2) agrees with the Queensland–New South Wales results (Thom & Chappell 1975), although many more radiocarbon dates are required to substantiate its correctness. After the eustatic low at 17 ka, sea-level initially rose very rapidly with deglaciation (167 cm per 100 years). At 9 000 B.P. sea-level, relative to the continental coast, stood at —25 m, and was within a metre of present sea-level between 5 000 and 6 000 B.P. Detailed work in Zululand (Hobday 1976) and the Saldanha area (Tankard 1976) has not revealed much evidence of Holocene shorelines higher than present sea-level. Furthermore, identification of the Late Quaternary datum in these areas at 8 m and 6 m respectively shows comparative stability during this period.

CONCLUSIONS

Pleistocene sea-level research is probably on the verge of a major revolution and studies such as that of Shackleton & Opdyke (1973) on isotopic compositional changes in the oceans should soon give us a clear account of glacio-eustasism through the Neogene and Pleistocene. Already this record, and the history of the existing ice sheets, show that glacio-eustatic sea-level could not have been much higher than present datum at any time in the Pleistocene. It will require a basic change in philosophy if the record of ocean isotopic compositions is to be accepted, and a reaction against these ideas similar to that which greeted the radiocarbon dating technique can be expected. In addition, it is clear that information on the effect of sea-floor spreading and tectono-eustasism in general is required.

Recent quantitative studies (e.g. Walcott 1972; Chappell 1974) show that the earth's crust responds isostatically to changing ice and water loads, and that the best place to observe the movement of sea-level relative to the ocean basins is on the midoceanic islands, which are remote from plate boundaries, and move with the ocean floor in its response to changing water loads.

Studies on Holocene shorelines along the continental margins take on a new dimension because of these recent trends. No longer is there need for absolute change in sea-level to explain shorelines of the last 6 000 years. By measuring differences in the Holocene record with locality on the continental margins, and comparing these with data from the midoceanic islands, for instance, we should have a means of examining the structure of the underlying mantle. Holocene shoreline studies will, in future, demand a more sophisticated understanding of sedimentary, marine and crustal processes than has been the case in the past in South Africa and elsewhere.

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THE OLDER COASTAL DUNES IN NATAL AND ZULULAND AND THEIR RELATION TO FORMER SHORELINES

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(With 5 maps)

ABSTRACT

In Natal and southern Zululand there extends along the coast a single dune-cordon, or in a very few places two fossil dune-cordons, in the rest of Zululand at least six. The older cordons are formed either of bright red sand or, close to the coast, of white cemented aeolianite, and are easily distinguishable from relatively unconsolidated low dunes of white, yellowish or light brown sand which have been formed recently, often by redistribution of the older sands. The main cordons were constructed during the earlier parts of glacio-eustatic regressions, the latest after the end of the Eem interglacial. They are not amenable to radiometric dating and are hardly ever fossiliferous; an attempt is made to date them by means of artefacts on or beneath them, by considering the marine terraces on which they rest, especially the lowest. It thus appears that the two cordons of Natal belong to the beginning of the last glaciation, with cores probably dating to the Saale glaciation; while the Zululand multiple cordons can be correlated with at least three glacio-eustatic regressions, as far back as the Elster or perhaps to an earlier glaciation. There is no reason to think that any of the extant dunes are older than the Pleistocene.

This paper has been condensed from three reports by the author written for the Tertiary/Quaternary Group of the South African Committee for Stratigraphy. The map was compiled for one of these reports, and contains more detail than is included in this text.

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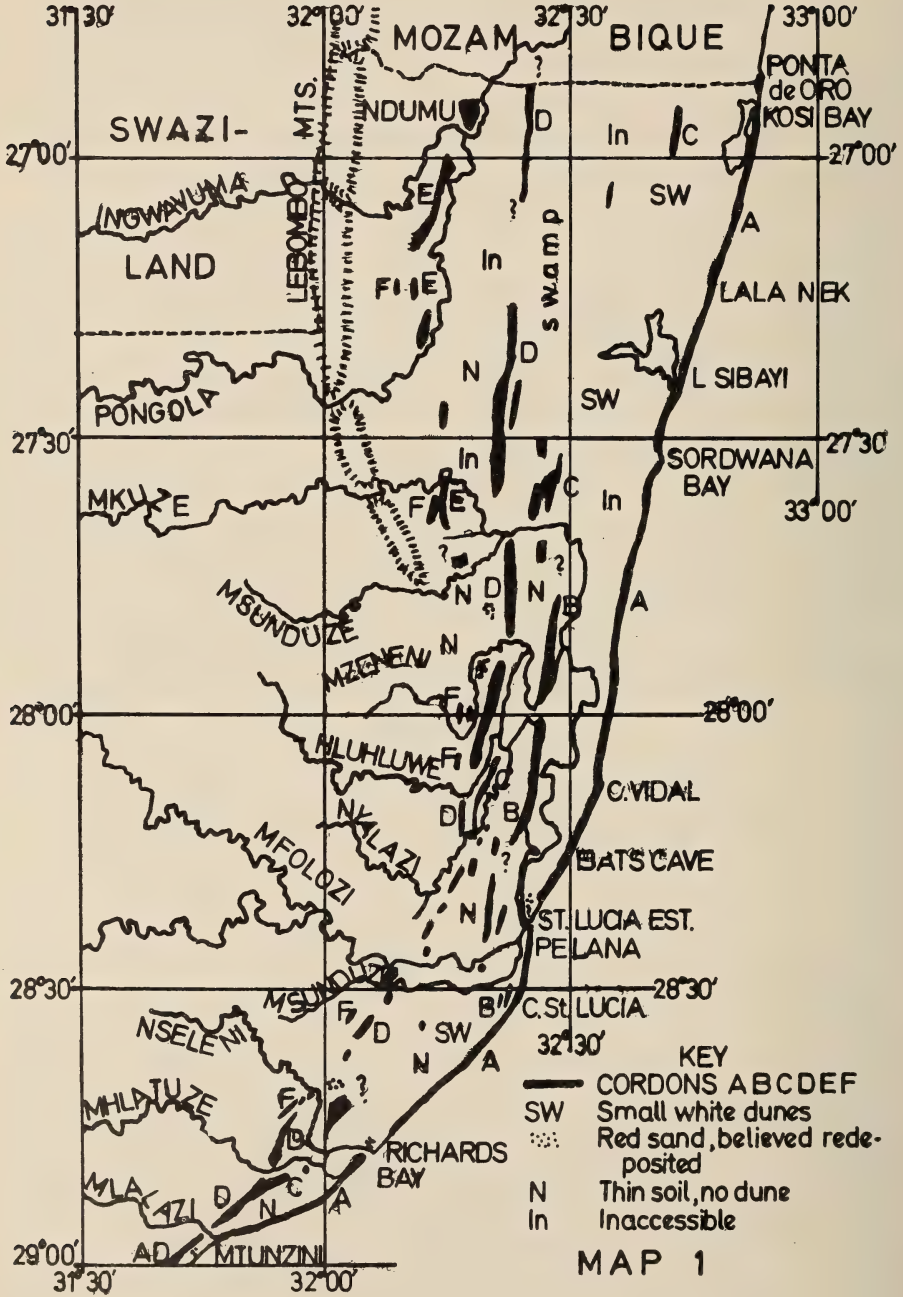
NATAL AND SOUTHERN ZULULAND

Despite much variation in relief, the coast of Natal is remarkably unindented. All along, from the Msikaba River in northern Transkei to the Mlalazi River in southern Zululand, there extends a dune-cordon, nowhere more than 5 km from the present shore, in places rising directly from it. Almost everywhere it is composed of bright red quartz-sand, in places containing ilmenite and magnetite. In depth the sand tends to yellowish or grey, but is not less consolidated than close to the surface. It seems to be mostly wind-transported, but in places there may be inclusions of clay from temporary vleis. In a very few places within Durban, such as Burman's Bush (King L. 1962; Frankel 1965) and Montclair (King L. C. 1966), there is hard white aeolianite in place of red sand. Tests of foraminifera in this rock indicate that the sand is at least partially of littoral origin. The Tertiary-Quaternary Working Group of the South African Committee for Stratigraphy has provisionally called this cordon the Berea Red Sands member of the Bluff formation.

Proc. sth. Afr. Soc. Quat. Res. 1975.
Ann. S. Afr. Mus. **71**, 1976: 19–32, 5 maps.


31°30′
32°00′
32°30′
33°00′
MOZAMBIQUE
SWAZILAND
LEBOMBO MTS.
NDUMU
PONTA de ORO
KOSI BAY
27°00′
INGWAVUMA
PONGOLA
swamp
LALA NEK
L. SIBAYI
27°30′
SORDWANA BAY
MKUZE
MSUNDUZE
MZENENI
28°00′
HLUHLUWE
NYALAZI
MFOLOZI
C. VIDAL
BATS CAVE
ST. LUCIA EST.
PELANA
28°30′
C. St. LUCIA
MSUNDUZE
NSELENI
MHLATUZE
MLALAZI
RICHARDS BAY
MTUNZINI
29°00′
A
B
C
D
E
F
N
In
SW
?
KEY
CORDONS A B C D E F
SW Small white dunes
Red sand, believed redeposited
N Thin soil, no dune
In Inaccessible

MAP 1

The top of this cordon is irregular, and it has undergone considerable erosion. In a few places it rises to > 150 m s.l. Its vertical thickness is variable; at the University of Natal not less than 70 m.[1] It is interrupted even by small rivers, nearly always at their lagoons which mark gorges grading to low glacio-eustatic sea-level; many of them had probably been incised before the last glaciation (Weichsel) and reactivated at that time. Landwards of the cordon are shallow valleys parallel to the coast, presumably cut after the cordon was first formed.

Except where incised by rivers, the cordon takes no account of underlying topography. It rests both on rock-slopes and on fossil beach-gravels; some of these gravels may be of Tertiary age (e.g. Umgeni Quarry, Clarewood Quarry; King L. C. 1966), but most contain rolled artefacts and were deposited during the Quaternary regression. The highest beach-gravel which has been noticed overlain by red sand is at > 101 m at Frasers; there are sites nearly as high at Malakazi and Ilfracombe (Davies 1970). The lowest site is at +6 m at Ngane Mouth, where a rock-platform at +5,5 m, perhaps a river-channel, is overlain by 70–80 cm of marine sand beneath dune-sand; in the gravel have been found rolled artefacts of Late Acheulian (Fauresmith) type. Red dune-sands rest on beach-gravel at +8 m at Tugela Mouth, +9 m at Sheffield Beach and Willard Beach, +8,5 m at Umdoni Park. There is no evidence at these sites that the sand has slumped. The writer assumes that the present cordon (discounting a possible older core) was formed as a single stage, after the +8–9 metre sea-level. Though we have no radiometric dates, the writer is inclined to equate this sea-level with the second peak of the last interglacial (Eem).[2]

As one would expect, there are no clean sections through the red dune. Two very deep gullies near Stanger (at Hyde Park and Kijabe), which cut right through it, are thickly overgrown and inaccessible. Nor have unconformities been observed normally within the dune. Excavations to 15–20 m depth at Overport and elsewhere in Durban reveal nothing but compacted sand. At Pigeon Valley Reservoir, behind the University of Natal, McCarthy (1967: 148, 197) observed traces of calcification about 14 m below surface, but no unconformity. At Hyde Park a terrace seems to be cut in red sand at +7,5 m. Though there is no clean section, a terrace at this altitude suggests a marine-cut platform, perhaps rather eroded, separating the main dune from an older dune, perhaps of Saale age.

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[1] This figure is calculated on the assumption that the Berea Cordon at this point rests on the 60–70 metre marine platform, as it does at the Mgeni and at the Tollgate; both east and west of the latter this platform was exposed some years ago. McCarthy (1967: 148, 197) describes an excavation at Pigeon Valley Reservoir just west of the University, but this did not reach rock.

[2] The evidence is set out in detail in Davies (1970) and Davies (1972) and cannot be repeated here. It is assumed on a world-wide basis that the peak of Eem I was at about +7 m and Eem II just above or just below 0 m; but the emergence throughout the Quaternary of the coastal regions of south-eastern Africa would produce higher levels for the Eem. There are two levels along these coasts, at about +18 and +9 m. The gravels on these terraces contain archaeological material, which can be roughly dated: on the 18-metre terrace both rolled and unrolled pieces which it is difficult to assign to a later stage than the Acheulian; on the 9-metre terrace rolled pieces which typologically are best assigned to the End-Acheulian. It is now being recognized that the Acheulian was giving place to more developed industries of Middle Stone Age type before the end of the Eem interglacial—not as sometimes claimed at the beginning of the interglacial. The archaeological evidence is confirmed by faunal evidence from the south-eastern Cape. Members of the warm-water Swartkops fauna occur in estuarine deposits at about +15 m and +6 m; these beds almost certainly belong to the 18 and 9-metre sea-levels. The fauna could not have survived a large drop of ocean-level for which in Italy and elsewhere there is evidence before Eem I; so these two sea-levels must be regarded as stages of a single interglacial.

At Umwabi Road, Isipingo, a sand-pit on the flank of a small valley which cuts through the red dune exposed marine terraces at +33 and +45m, separated by a cliff formed of a dyke of rotten dolerite which must have emerged as a stack above the upper terrace, which is cut in shale (Maud 1968: 167; Davies 1970: 406, 419, 425–6; section no longer cleanly exposed). Banked against the cliff was yellowish sand with layers of ferricrete and ilmenite. This was overlain by a surface of shale chips and a few unrolled artefacts, one probably a hand-axe. Both terraces and this surface were covered by dune-sand, red passing into yellow in depth, to an altitude of +82 m, with a line of quartzite pebbles on it such as frequently occur on the main Berea Cordon and are probably manuports. It appears that the lower sand against the cliff was the remains of an older cordon which had been almost entirely removed, perhaps in the last interglacial.

Most of the exposures on top of the main Berea Cordon have suffered erosion in the past, and reveal a mixture of cultural material which may date from any periods after the cordon was formed. But on a few two surfaces are visible. The lower is 1–3 m below the surface of the red sand; it carries picks and other artefacts of the Tugela Industry.[3] The upper line is on the surface of the red sand, and carries artefacts of Pietersburg affinity (probably Sampson's (1972) M.S.A. Phase 3). It therefore appears that since the last interglacial there were two stages of dune-construction, separated by an unconformity.

In a large exposure at Umgababa ilmenite-quarry there is evidence for stratification of the dune which can be reconstructed as follows:

1. On the quarry-floor at about +45 m bright red sand, perhaps older dune, with a sloping surface carrying stone chips, nodules and Late Acheulian artefacts. The base of the sand is not exposed, so it is not known if it rests on a beach or on a rock-slope.[4]
2. Above the lower red sand, up to 6 m of bright red sand capped by a surface with terrestrial molluscs, root-tubes and artefacts of the Tugela Industry.
3. On this surface, up to 18 m of whitish calcified dune, capped by a layer of ferricrete nodules containing flakes, points and other artefacts of Pietersburg type.
4. On this surface, soft red sand passing conformably into grey humified sand.

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[3] Formerly Sangoan; but the writer has come to the conclusion that this name is not justified for the Natal coast (see Davies 1976)

[4] McCarthy (1967: 196) gives a schematic section, clearly not based on direct observation, indicating that in his view the red sand rests on pebbles on the seaward-slope of the 18-metre shoreline.

The calcified sand which here separates the Tugela from the Pietersburg surface is thicker than the upper red sand found elsewhere between the two surfaces; but the contemporaneity of each surface at different places is guaranteed by the artefacts. McCarthy (1967: 192–6) misinterpreted the Umgababa site because he relied on dubiously datable foraminifera and took no account of the archaeological evidence (see Davies 1976).

In some places, for instance at the Upper and Lower Red Deserts, Port Edward, there are two discrete areas of red dune; but the writer considers that, apart perhaps from an older core, the Berea member is a single cordon which has in places been subdivided by erosion. There are, however, remains in Natal of an outer cordon, for which has been recommended the name Calcarenite member of the Bluff formation.

The Bluff Cordon is in places submerged as an offshore reef (e.g. Aliwal Shoal; McCarthy 1967: 136–7). Only at Durban Bluff are all three beds preserved:

Bed 3. Lightly calcified aeolianite with pipes and nodules, nearly 100 m thick and rising to a maximum of +106 m. It apparently contained vlei-beds and lenses of boulders, perhaps pieces of cemented sandstone, but no continuous unconformity. Near the surface are unknown thicknesses of decalcified red sand (see King & Maud 1964: 21–2).

Bed 2. A beach less than 1 m thick, composed of boulders, shells and sand. At Cave Rock it rises to a maximum of +8,1 m and dips steeply seaward. At Mbokadweni Mouth and Umhloti Beach (see Maud 1968: 177–9) there were apparently fluctuations of sea-level soon after the start of the regression, but the sequence of these events has not been fully elucidated.

Bed 1. A very hard aeolianite down to —90 m, resting in places on Karoo rocks, elsewhere on planed Cretaceous beds.

Bed 2 occurs only on the seaward face of the Bluff, at Umhloti Beach and Tiger Rocks. Where it is absent, e.g. at the Point, the contact of beds 1 and 3 is not clear and there is no obvious unconformity. Bed 1 probably rose higher than +8 m where not marine-planed, perhaps considerably higher, as on its face has been found slumped sand, equally calcified and containing stone chips and mammal-bones.

Except along the Bluff, bed 3 is missing and bed 2 is truncated. On the offshore reef presumably bed 1 also is truncated.

It is likely that at Durban, as elsewhere, the 8-metre beach correlates with the second peak of the last interglacial. There is no sign in Durban of the first peak, perhaps to +18 m, except far up the Mgeni Estuary. The fluctuations below the 8-metre beach may cover the third peak (cp. Suggate 1974). If this dating is correct, the lower aeolianite or bed 1 of the Bluff formation was formed during the eustatic low of the penultimate (Saale) glaciation, the upper aeolianite or bed 3 during the Weichsel glaciation.

Practically no artefacts have been found in the Bluff beds. There was one pick of Tugela-type in the beach, perhaps one or two on a river-flat behind the beach; but on the surface of the Bluff Ridge nothing older than Wilton.

The highest beds of both Berea and Bluff Cordons rest on a beach at +8–9 m, and probably belong to the same age; perhaps the seaward cordon is a little later than the landward. A pause in dune-construction could have been due to restriction in the supply of sand caused by a marine transgression which flooded much of the continental shelf. It is unlikely that this transgression was the third peak of the last interglacial, because between the second and third peaks the sea probably did not regress far enough to supply sand for the whole of the Berea Cordon; so the transgression may have been that of the Brörup interstadial.

Therefore, with great hesitation owing to the absence of typical artefacts on and in the Bluff Ridge, the writer would propose the following chronology for the Natal dunes: the most active period of dune-formation would be the earlier part of a marine regression, when supplies of sand on the continental shelf were being continually exposed but only slowly anchored by pioneer vegetation. Changes of prevailing wind and rainfall during the onset of a glacial period may also have contributed:

After the mid-Weichsel transgression (Dennekamp–Hengelo). Partial decalcification of Bluff bed 3 and of bed 3 at Umgababa.

Roughly at the mid-Weichsel interstade. Upper dune-surface with Pietersburg-type industry.

Between the Brörup and mid-Weichsel interstades (about 60 000 and 35 000 B.P.). Construction of the Bluff upper aeolianite, of Umgababa bed 3, and of the upper red sand on the Berea Cordon.

Before the Brörup interstade (before 60 000 and perhaps as early as 80 000 B.P.). Tugela Industry on the lower surface of the Berea Cordon and on the still exposed 8-metre beach of the Bluff (bed 2). Construction of the principal body of the Berea Cordon.

Third peak of the last interglacial (*c.* 80 000 B.P.). Sea-level near modern.

Between second and third peaks of the last interglacial (*c.* 107 000–80 000 B.P.). Sea-level a little below modern.

Second peak of the last interglacial (*c.* 107 000 B.P.). Formation of the 8–9 metre beach.

L. C. King's suggestion (1966) that Uloa (Map 3 o13) and other beds in the Mfolozi Estuary, the Bluff beds and the outcrops of calcareous sandstone in the Berea Cordon in Durban are all Pliocene is unacceptable. The detailed foraminiferal reports which he quotes in this but not in subsequent papers say for the Mfolozi series 'Age; Pliocene or younger', for the Durban series 'Age: None given'. To argue from these reports that all these occurrences are Pliocene is illogical. As the Miocene beds at Uloa and other Zululand sites are close to modern sea-level, the writer would agree that there has been a post-Miocene transgression to >150 m, the highest known level of the Pliopleistocene shorelines in Natal (Davies 1970); some of the calcified beach-deposits in Durban, especially on terraces which on altitude do not fit into the established Pleistocene regressive sequence, may belong to the transgression. But the presence of Middle Pleistocene artefacts within beach-gravels beneath the calcified patches of dune excludes the possibility that any of the calcified dunes belong to the Miopliocene stage.

CENTRAL AND NORTHERN ZULULAND

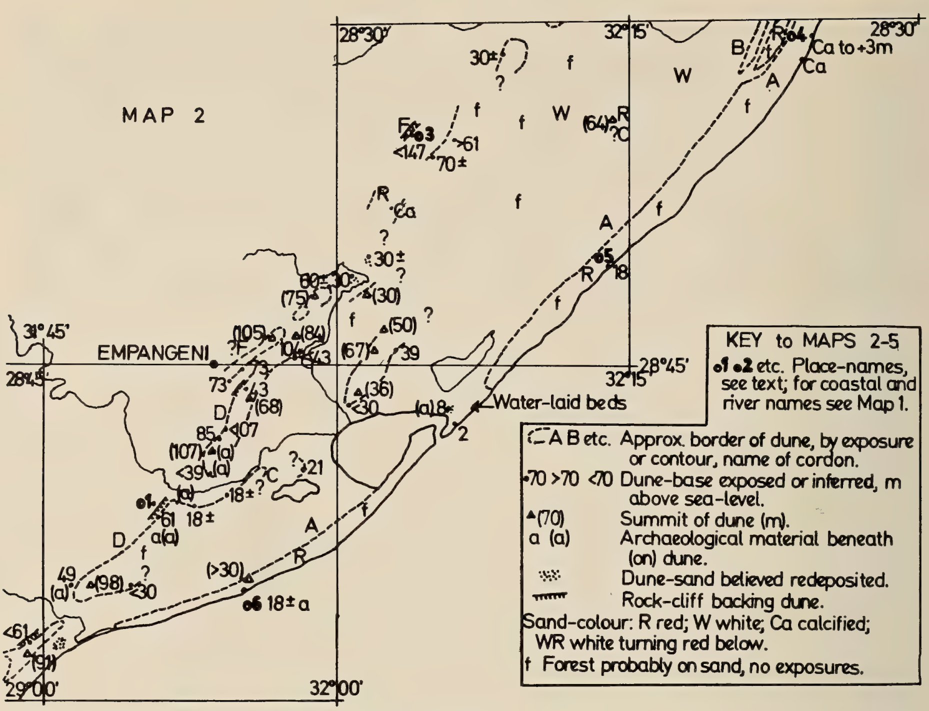
North of the Mlalazi River the Zululand coast trends from north-north-east to north-east to form a wide coastal plain bounded landwards by the Lebombo Mountains. The northern part of this plain is composed of Cretaceous rocks with perhaps a Tertiary veneer, marine-planed and then lightly dissected; the planation has extended a short way into the basalts. In the southern part the Cretaceous has been largely submerged beneath younger sediments, and there are lagoons and swamps which have been isolated fairly recently from the sea. The Pliopleistocene shoreline is a long way inland, nearly 100 km near the Mozambique border.

At least six cordons of red dune-sand can be identified in the coastal plain, besides a large number of lower and shorter dunes of brown, yellow or white sand, perhaps formed by redeposition; there may be more than six cordons, but heavy afforestation in the south makes it impossible to trace some of the cordons over long distances, and much of the northern area is trackless grassland and inaccessible. It is presumed that each cordon was constructed not far from the contemporary shore. Lack of exposure makes it difficult to determine their bases. They do not rest each on a single shoreline, but there has probably been slumping into valleys as they graded to fluctuating sea-levels.

Cordon A, the coastal cordon, follows the present coast closely. Both faces are steep. It rises to a maximum altitude of +145 m. It is interrupted only at four river-mouths (Mhlatuze and Nseleni, Mfolozi and Msunduze, Sordwana Bay, Kosi Bay). At Mission Rocks (just south of Bats Cave) and Lake Sibayi it overlies fossil mouths, marked by up-country pebbles in beach-rock which was formed during or perhaps before the last interglacial. It may rest on well-cemented beach-sands which incorporate older aeolianite pebbles, in some places at +1–2 m, at Bats Cave at +8 m, at Black Rock (Map 5 o5) at +12 m; also on uncemented marine or lagoonal sands at +18 m at Mbonambi Beach (Map 2 o5) and Port Durnford (Map 2 o6; Hobday 1975). At Kosi Bay cemented aeolianite rested on calcified beach-sand at −3 m. While Cordon A may incorporate fragments of an older cordon, in its present form it seems to post-date the 18-metre sea-level. It may well be younger than the 8-metre level; but nowhere is the cliff of the underlying beach exposed.

An entrenched channel north of Cape Vidal (Hill 1975), which apparently drained Lake St Lucia to the north-east, must be older than the fossil mouth at Mission Rocks and was probably blocked by a cordon older than the 18-metre sea-level.

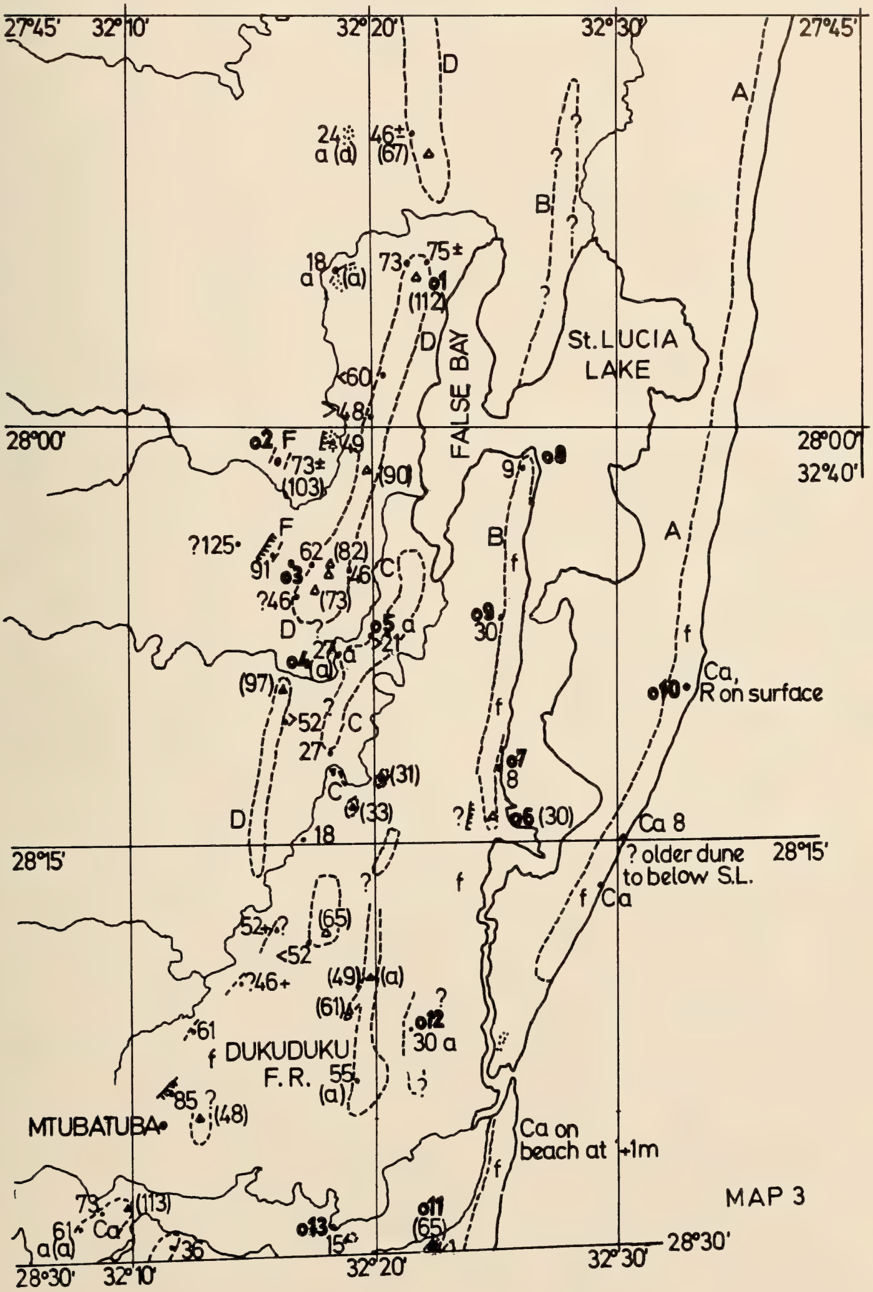
Cordon A seems to be formed of red sand; but in places there is evidence


MAP 2
28°30'
32°15'
28°30'
31°45'
EMPANGENI
28°45'
32°15'
Water-laid beds
29°00'
32°00'
W
f
R
Ca to +3m
Ca
A
B
C
D
KEY to MAPS 2-5
•1 •2 etc. Place-names, see text; for coastal and river names see Map 1.
A B etc. Approx. border of dune, by exposure or contour, name of cordon.
•70 >70 <70 Dune-base exposed or inferred, m above sea-level.
▲(70) Summit of dune (m).
a (a) Archaeological material beneath (on) dune.
Dune-sand believed redeposited.
Rock-cliff backing dune.
Sand-colour: R red; W white; Ca calcified; WR white turning red below.
f Forest probably on sand, no exposures.

of calcification, at Meersig Quarry (Map 3 o10) up to +65 m s.l. and at no great depth from the summit. Its composition therefore resembles Durban Bluff. But though no artefacts have been found beneath Cordon A and fossils very rarely, a stone pick of the Tugela Industry was found by D. K. Hobday on the dune at Port Durnford. Behind the village of Richards Bay there seemed to be evidence, at the back of the cordon, for two stages of slumped red sand separated by a ferricrete layer; on the lower sand were two rolled pebbles which must be manuports, on the upper a pick. Though exposures are rare on Durban Bluff and no watch was kept on the widespread building twenty years ago, in fact no piece of the Tugela Industry has been found on the ridge; so Cordon A in Zululand may in part be slightly older than the Bluff Ridge.

Cordon B can be traced along the west side of Lake St Lucia. At Charters Creek (Map 3 o7) and Hell's Gate (Map 3 o8) it rests on a platform at +8–10 m, at Mpathe F.R. (Map 3 o12) and Fanies (Map 3 o9) on water-laid beds at +30 m. South of Malakatana (Map 3 o6) it apparently diverges southwestwards, follows the eastern side of the Mpate valley, is interrupted by the Mfolozi Estuary, and resumes at Sokulu (Map 3 o11) and Red Hill (Map 2 o4), where it diverges from Cordon A. Its base is at about +25 m on both banks of the Mkuze River near Lower Mkuze Store (Map 4 o3). It cannot be traced north of 27.30 S, but may continue as one of the inaccessible dunes west of Maputa (26.59 S 32.45E).

Cordon B is formed of red sand. No artefacts have been found on it, other

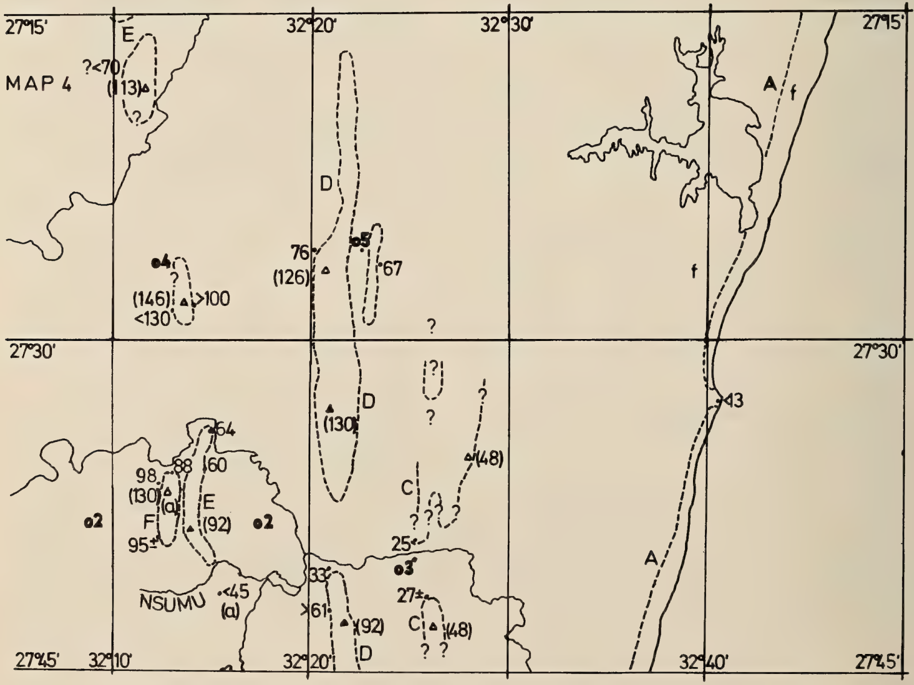

27°45'
32°10'
32°20'
32°30'
27°45'
D
A
24 a (d)
46± (67)
B
?
St. LUCIA LAKE
FALSE BAY
18 a (a)
73
75±
o1 (112)
D
<60
>48
28°00'
o2 F
49
73± (103)
(90)
o8
9
28°00'
32°40'
?125
F
91
o3
62 (82)
46
C
?46
(73)
B
f
A
D ?
o5 a
21
o9 30
27 a
o4 (a)
(97)
f
o10
Ca, R on surface
>52
C
27
o7 8
(31)
C
(33)
?
o6 (30)
D
18
Ca 8
28°15'
? older dune to below S.L.
28°15'
?
f
f Ca
52
(65)
<52
?46+
(49) (a)
(61)
?
o12 30 a
61
f
DUKUDUKU F.R.
55 (a)
85 ?
(48)
MTUBATUBA
Ca on beach at +1m
f
73
(113)
61 Ca
a (a)
36
o11 (65)
o13
15
1
28°30'
32°10'
32°20'
32°30'
28°30'

MAP 3

than fairly recent material. Beneath it the writer found at Mpathe F.R., on a surface formed partly of water-laid grit and partly apparently of older dune, broken pebbles of nondescript type. As Cordon B rests in places on the 8–10 metre terrace, it must be younger than one peak of the last interglacial.

Cordon D can be traced fairly continuously from the Mlalazi River probably to the Mozambique border. It is interrupted by several rivers, and in the far north is mostly inaccessible. It is formed of red sand. Its sides are not steep, and it rarely rises to a great height above the adjacent plain. Its maximum altitude is +112 m south of Mtubatuba and at Kuleni (Map 3 o1), +130 m north of the Mkuze River (see Map 4). Its base is generally between +60 and +75 m, nowhere below +30 m save where it seems to have slumped. In places it rests on one of the higher beach-gravels (+49–+70 m).

Cordon D appears to be aligned with a cordon behind Mtunzini, which rests on rock at +61 m. South-west from Mtunzini there is a single cordon, which appears to belong to the Berea member. It is, however, difficult to associate Cordon D with the Berea Cordon, which the writer has shown to date from the last interglacial. Cordon D is 22 km from the present coast near Mtubatuba, >35 km behind Kosi Bay. Its profile is much less steep than the Berea Cordon. On it have been found a very few artefacts—in addition to pieces of the Tugela Industry, a hand-axe at the University of Zululand (Map 2 o1) and a small cleaver near the Mlalazi River; these are likely to be Late Acheulian and older than the last interglacial. Beneath the dune have been



found rare pieces of some stage of the Acheulian. Near the Mhlatuze River there is a surface 3 m below the top of the red sand, indicating reworking or renewed dune-building during the last glaciation.

It appears therefore that Cordon D is continuous with the older core of the Berea Cordon, revealed at Umwabi Road, Durban; whereas Cordons A and B correlate with the present Natal cordons, and were formed after the last interglacial.

Cordon C is a discontinuous line from south of the Mhlatuze River to the promontory on the south side of False Bay. Possibly the outer dune at Tshongwe (Map 4 o5) is part of it. North-east of Mtubatuba there may be included in it more than one cordon. It rests at >21 m on an estuarine gravel of the Nyalazi River and farther south on a platform at +27 m.

Cordon C seems to be older than the 18-metre shoreline. Both it and Cordon D may have been constructed just after the 30-metre shoreline in the Mfolozi basin; but farther north, where the Cretaceous shelf is higher, there is only one cordon. There is no satisfactory archaeological evidence for dating Cordon C. There have been found on it in Dukuduku F.R. a few indeterminate artefacts possibly of Tugela affinity; at Hluhluwe Bridge (Map 3 o4) and Nyalazi Dip (Map 3 o5) it was impossible to tell if the artefacts had come from beneath or above the red sand.

Cordons E and F are fragmentary. It is often difficult to decide which cordon is represented, and there may be remains of more than two cordons west of D. Hesitatingly the writer has plotted as Cordon E a prominent ridge extending from the Mozambique border and Ndumu Hill, west of the Pongola River past Nkononde (Map 4 o4) into Mkuze Game Reserve (Map 4 o2); it has not been identified south of the Msunduze River. It rises to +189 m near Makhane's Pont (Map 5 o4) and +175 m at Ndumu, and in places >70 m above the adjacent plain. In the extreme north its base is at about +100 m. West of the Pongola River and in Mkuze Game Reserve it rests on the inner edge of the 60-metre beach. Between the Nsumu and Msunduze Rivers its base seems to be at <45 m; but the area is very difficult of access, so it has not been possible to control information obtained in 1950.

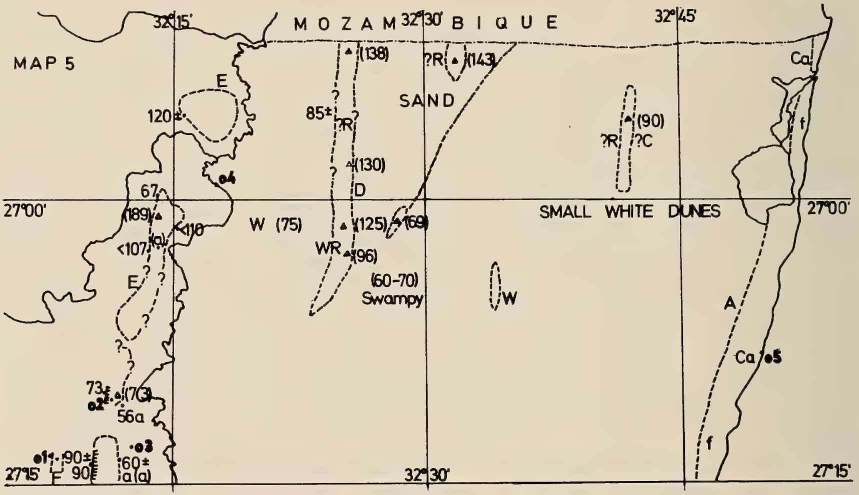
Nor can Cordon E be archaeologically dated save within wide limits. The 60-metre beach-gravel has yielded rolled choppers of adiagnostic type at Mzinyeni Dip (Map 5 o3) and Mlambongwenye (Map 5 o2) (Davies 1970). On the dune south of the Nsumu River there were found lightly abraded rough hand-axes.

Although Cordon E is well preserved, it appears to date to an earlier interglacial-glacial cycle than Cordon D, the two being up to 15 km apart. If D with fragments of C belong to the Holstein–Saale, E may date to the Cromer–Elster cycle or to an unrecognized interglacial during the Elster.

Cordon F is almost certainly older than E. In Mkuze Game Reserve, where it can be distinguished from E, it is 30 m high and its base is at +95 m. Elsewhere it is fragmentary, and in many places all that is preserved is a low body of red sand banked against a cliff. The writer has assigned to it fragments with base as follows:

Empangeni	+73–+104 m
Homeleigh against a cliff (Map 2 o3)	+147 m
Ncemane against a cliff (Map 3 o3)	+90 m
Hluhluwe (Map 3 o2)	+73 m
Mkuze Game Reserve (Map 4 o2)	+95 m
east of Lubombu Drift (Map 5 o1)	+90 m

It seems therefore to rest on surfaces at +73 m and +90–+100 m. The cliff at Ncemane is the most probable indicator of its altitude—i.e. it is associated with a marine platform at about +90 m; but it is possible that really two cordons are represented. There is no archaeological evidence for dating Cordon F; but there is no reason to suppose that any part of it is pre-Pleistocene.



CONCLUSION: SUGGESTED PLEISTOCENE CHRONOLOGY

All the cordons in Natal and Zululand were probably constructed during marine regressions, which uncovered abundant sand on the continental shelf. Their formation was probably rapid, as they do not include well-marked land-surfaces. So each dune was for a time mobile, but owing to changing conditions became fixed by vegetation. Fixation may have been due to continued regression, which removed the shore so far that beach-sand no longer reached the dune; but partial transgression, change of prevailing winds or aridity could reactivate it. So far as we know, the deepest regressions round the emerging sub-continent were in the Saale and Weichsel glaciation-cycles. To each of these cycles there are assigned two cordons, and there may be others offshore.

Lack of informative exposures makes it difficult to study these dune-cordons. Natural drainage has incised the dunes but left slumped and heavily vegetated scars. Industrial development has seldom cut straight through a cordon to reveal a clean section. We can reasonably identify events of the last cycle (Eem–Weichsel) from the lowest terraces on which the dunes rest and from artefacts which by then had become more differentiated; during older cycles, artefacts are much less diagnostic.

Provisionally the author would propose the following table:

Last cycle, Eem/Weichsel, with 3 interglacial peaks of sea-level followed by deep regression	Natal, Berea Cordon; Natal, Bluff bed 3; Zululand, Cordons A and B	On dunes, Tugela and later industries; beneath dunes, Late Acheulian and earlier
Penultimate cycle, Holstein/Saale	Natal, core of Berea Cordon; Natal, Bluff bed 1; Zululand, Cordons C and D; aeolianite pebbles incorporated in beach-rock of last interglacial	On dunes, Acheulian
Antepenultimate cycle, Elster or Cromer/Elster	Zululand, Cordon E	Beneath dunes, pre-Acheulian

APPENDIX

Maps are included only of the complicated areas of Zululand, where there are several cordons. South of the Mlalazi River at most places only a single cordon occurs. To enable the reader to find localities mentioned in the text, a list of their latitudes is given:

Aliwal Shoal	30°15′
Burman's Bush	29°49′
Clarewood Quarry	29°55′
Frasers	29°33′
Hibberdene road-cuttings	30°32′
Hyde Park	29°19′
Ilfracombe	30°11′
Isipingo, Umwabi Road	29°59′
Kijabe	29°25′
Malakazi	30°00′
Mbokadweni Mouth	30°01′
Montclair	29°55′

Msikaba Mouth	31°19′
Ngane Mouth	30°11′
Port Edward red deserts	31°04′
Sheffield Beach	29°29′
Tiger Rocks	30°01′
Tugela Mouth	29°13′
Umdoni Park	30°24′
Umgababa ilmenite quarry	30°08′
Umgeni Quarry	29°49′
Umhloti Beach	29°40′
Willard Beach	29°31′

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ROCKY BANK—EVIDENCE FOR A RELICT WAVE-CUT PLATFORM

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(With 12 figures and 1 table)

ABSTRACT

Rocky Bank is an isolated rocky outcrop 10 km south-east of Cape Point. Between 30 and 40 m below sea-level, a wave-cut platform is sparsely covered with well-rounded pebbles, cobbles and boulders of Table Mountain Sandstone. The extremely low quartz content in the sediments on the platform indicates that there is no marine abrasion active today. This supports evidence from other parts of the world that the abrasive energy of ocean waves is restricted to depths shoaler than 12–15 m. Calculation of orbital velocities from local wave conditions demonstrate the concentration of wave energy near the sea surface. To account for the wave-cut platform and its features a sea-level 20–25 m below the present must be assumed. This agrees well with other observations along the west coast of southern Africa.

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INTRODUCTION

Rocky Bank is an isolated rock outcrop about 10 km (6 nautical miles) south-east of Cape Point at the mouth of False Bay, Western Cape, South Africa. The geographic position of its shallowest part is 18.35,5S, 24.24,8E.

The outcrop has been traversed on several research cruises in the past but no samples were recovered to establish its lithology or the nature of its sediment cover. To fill this gap an *in situ* investigation was arranged during the winter months of 1973. Besides obtaining this initial geological information, clear evidence was found that Rocky Bank represents a wave-cut platform not exposed to submarine abrasion under the present hydrological conditions. To explain this feature a lower sea-level must be assumed.

This study presents the evidence that characterizes the wave-cut platform and proves its present non-activity. The implications of such evidence with respect to the methodological difficulties experienced when attempting to infer former sea-levels from raised marine terraces are discussed.

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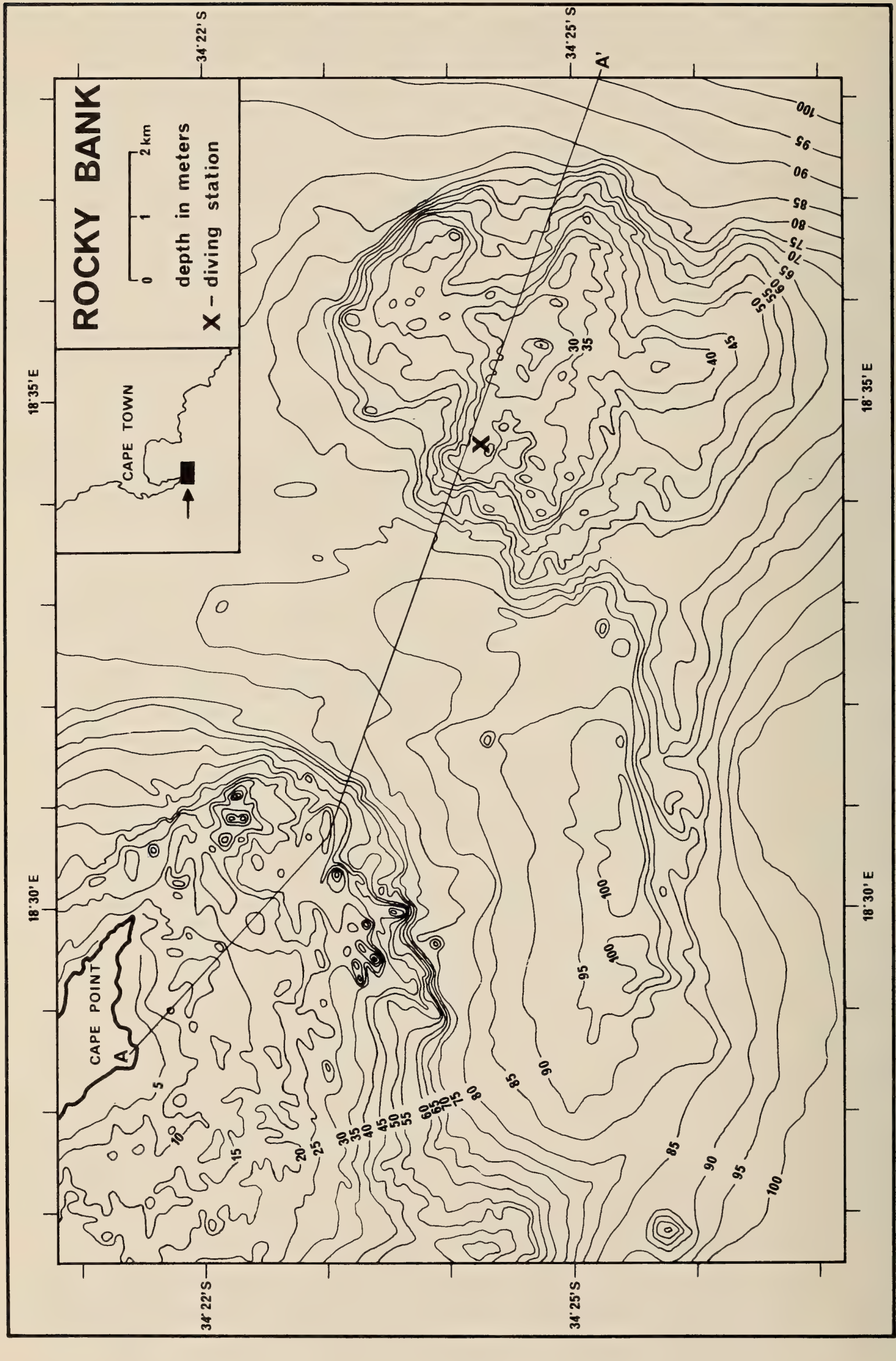


Fig. 1. Rocky Bank—locality and bathymetry.

First results of this investigation were reported in the annual technical report of the Marine Geology Unit at the University of Cape Town (Flemming 1973). Since then new information has been obtained by side-scan sonar and shallow seismic profiling, clarifying some of the problems that had remained unsolved.

METHODS

Observations, documentation and sample collection was carried out *in situ* by the application of SCUBA diving. Notes and sketches were made on plastic sheets. These included strike directions measured by compass, and dip angles measured with a spirit-level clinometer. The photographs were taken with a Nikonos II underwater camera. Sediment samples were recovered by short hand-operated corers in order to minimize sampling errors. Finally, pebbles and cobbles as well as bed-rock chips were collected for closer inspection.

Laboratory work (viz. Müller 1967) included dialysis, drying and sieving of the sediment at half-phi intervals. Each fraction was then inspected under a binocular microscope. Seven different component groups were identified, separated, counted and weighed. Very small numbers of coralline algae and worm tubes, too few to allow accurate weighing, are grouped together with bryozoans. Similarly, even smaller numbers of unidentifiable fragments are grouped with cirripeds which constitute 61 per cent of the total sample, thus avoiding distortions in the final results.

In this way the whole sample was processed down to the 1,5–2,0 phi fraction. The remaining four fractions total only 0,23 per cent by weight and the individual components were too small to weigh accurately. All presentations are therefore true weight percentages of the total sample. The grain size parameters were determined according to the graphic measures proposed by Folk & Ward (1957) and Friedman (1962).

MORPHOLOGY

Rocky Bank rises rather steeply from the surrounding sea-bed reaching a maximum slope gradient of 1 : 7. At about 40 m below sea-level the slope begins to level off into a rugged plateau which gives the outcrop a guyot-like appearance interrupted only by a small central peak which reaches 22 m below surface (Fig 1).

The surface area of the plateau, enclosed by the 40 m depth contour, amounts to 7,65 km^2 or 32 per cent of the total surface area projected by the 65 m contour amounting to 24 km^2. When plotting the relative frequencies of projected surface areas at 5 m intervals (Fig. 2) a first sharply defined maximum is reached between 35 and 40 m (A). A second less conspicuous maximum lies between 55 and 60 m (B). Two platforms are therefore clearly defined.

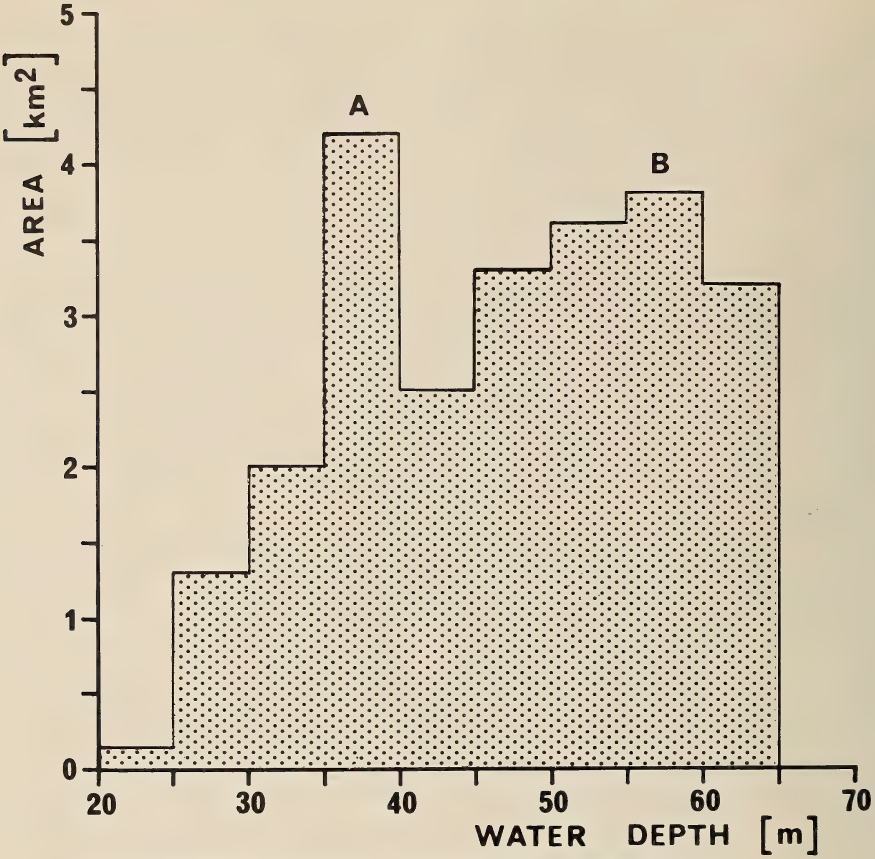


Fig. 2. Frequency histogram of projected surface areas at 5 m intervals.
Maximum A—35–40 m platform
Maximum B—55–60 m platform

GEOLOGY

The *in situ* investigation confirmed the previous assumption that Rocky Bank consisted of Table Mountain Sandstone (Gentle 1970). This was by no means obvious as it would not have been surprising if it were actually found to be a granite outcrop (Fig. 12).

At —35 m the submerged 'landscape' gave the impression of a rugged yet relatively level plateau dissected by shallow irregular gullies (Fig. 3). The sandstone formation dips gradually to the south-west with a general north-westerly to south-easterly strike. The gullies do not reflect the strike of the bedding but run more or less at right angles to it. It seems hardly coincidental that the orientation of these gullies is parallel to the direction of the dominant south-westerly swell which is refracted by Rocky Bank (Shipley 1964). It is possible that at some stage wave action has selectively eroded a major joint

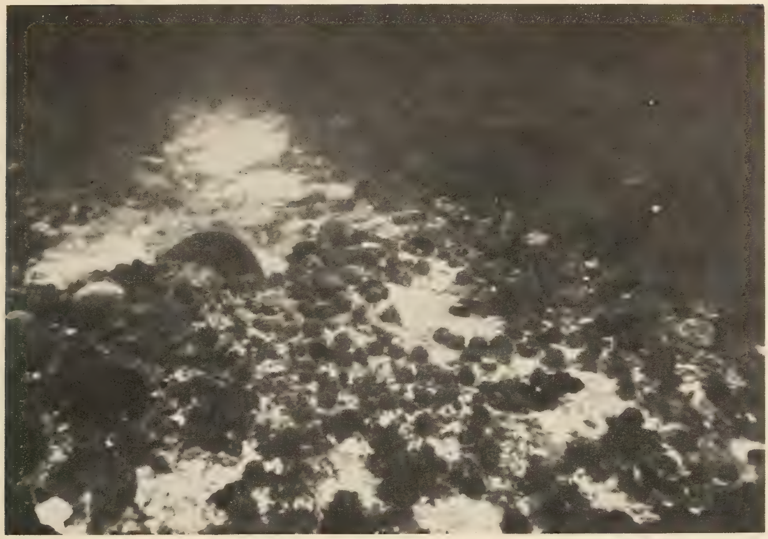


Fig. 3. The rugged yet relatively level plateau at −35 m.

direction. The plateau is loosely covered by well-rounded pebbles, cobbles and boulders most of which are overgrown by calcareous algae and other marine organisms (Fig. 4). Biogenic sediments, often forming patches of several square metres, are usually confined to the gullies (Fig. 5) but occasionally occur between boulders also (Fig. 4).

Side-scan sonar recordings show that all of Rocky Bank consists of sandstone and it remains uncertain at what depth the contact to the granite takes place. From 60 m downward the whole outcrop is mantled by a belt of sediment attaining a fan-like shape especially along the eastern flank. Boomer profiles record this sediment fan as a transparent wedge. However, they also reveal an abrupt change in the slope of the bedrock at 90 m below sea-level, possibly indicating a third wave-cut platform.

SEDIMENTS

The sediments of Rocky Bank are almost entirely of biogenic origin; the terrigenous content being merely 0,37 per cent by weight. The distribution of this sediment cover, consisting predominantly of coarse sands and fine gravels, is thin and patchy with a tendency to sheet accumulations in low depressions and gullies. This paucity of sediment can only be explained by low production rates and probably gradual transport across the platform into deeper water by the combined forces of wave action, gravity and possibly currents. Sediment movement is in fact clearly illustrated by well-defined ripple marks that reach heights up to 15 cm and crest-to-crest distances well in excess of 60 cm (Fig. 5).

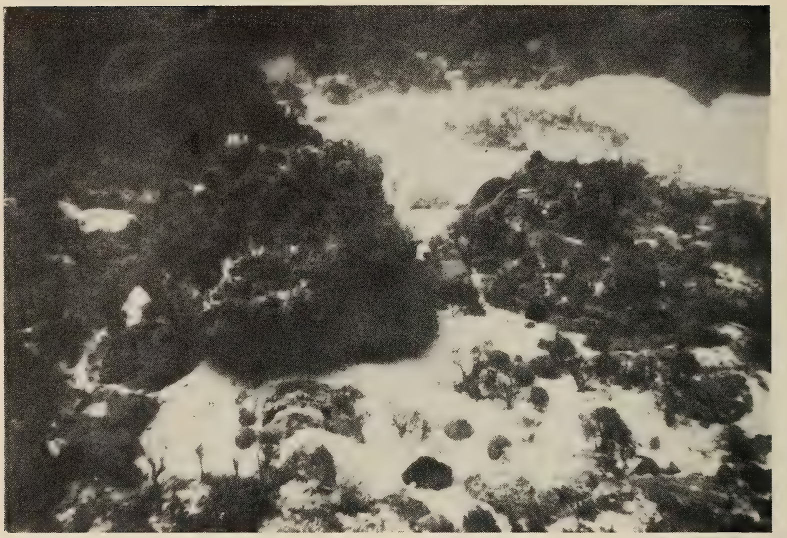


Fig. 4. Well-rounded pebbles and cobbles with coarse biogenic sediment patches over bedrock.

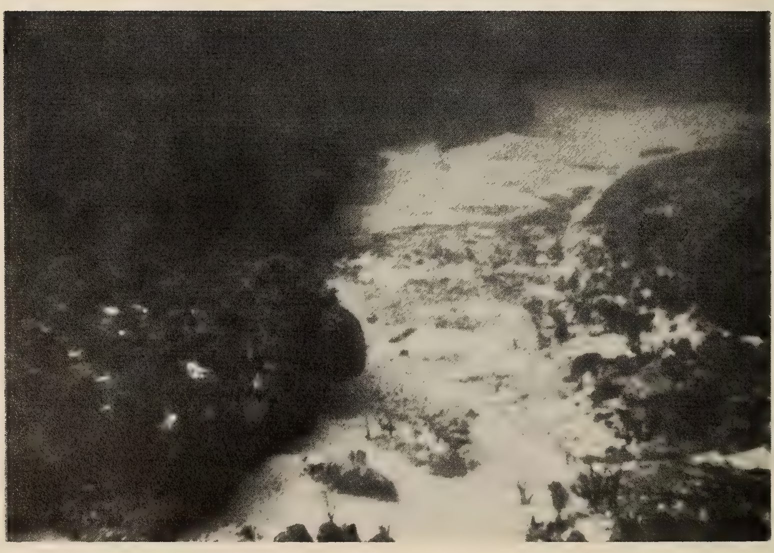


Fig. 5. Gully in bedrock with coarse biogenic sediment. The ripple marks indicate water movement.

The Recent sediments along the lower slopes of Rocky Bank should therefore consist essentially of fragmented carbonate skeletons produced on the upper reaches of the bank, becoming increasingly diluted by pelagic sediments. Further down in the sedimentary column of the fan coarse sands, pebbles, cobbles and boulders, produced in the high energy environments of a lower sea-level, can be expected.

Pertinent grain size parameters are listed in Table 1 below. The lognormal grain size distribution is demonstrated by the identical values for median, mean and mode.

TABLE 1.
Grain size parameters

Median	— 0,90 phi (very coarse sand)
Mean (Folk & Ward 1957)	— 0,90 phi („)
Mode	— 0,90 phi („)
Std. Deviation (Folk & Ward 1957) . . .	+ 1,02 phi (poorly sorted)
Skewness (Friedman 1962)	— 0,03 (nearly symmetrical)
Kurtosos (Friedman 1962)	+ 0,69 (platykurtic)

The corresponding cumulative curve and frequency histogram are presented in Figure 6A and B respectively. Poor sorting is a common feature of most biogenic sands when processed mechanically by sieving. Settling results show that the same sediment is hydraulically equivalent to well-sorted coarse quartz.

The weight distribution of the sediment components is threefold, being dominated by cirriped fragments (61 per cent). A second group is formed by bryozoans (20 per cent) and molluscs (15 per cent) and a third group is made up of echinoderms (2 per cent), corals (1,2 per cent), quartz (0,37 per cent) and benthic forams (0,2 per cent). Figure 7 illustrates this relative frequency very clearly. The size distribution of each individual component also follows the lognormal pattern, indicating their selective response to the hydraulic sorting process. Only corals deviate from this pattern. They seem to reflect only the finer tail of an otherwise much coarser population not sampled representatively (Fig. 8). The contribution of these individual components to the sediment is summarized in a composite frequency polygon (Fig. 9).

The composition of the sediment allows interesting conclusions regarding the ecological conditions on Rocky Bank. This, however, is not the aim of this paper. On the other hand it also provides powerful evidence for a non-active abrasion platform, an aspect to be discussed in the following section.

DISCUSSION

Although pronounced submerged terraces always suggest wave-cut platforms, such features alone do not justify this conclusion. Tectonic activity cannot always be ruled out. In the case of Rocky Bank, however, the presence of well-rounded pebbles, cobbles and boulders provides the necessary evidence for a wave-cut origin; at least for the upper platform. Too little is known about

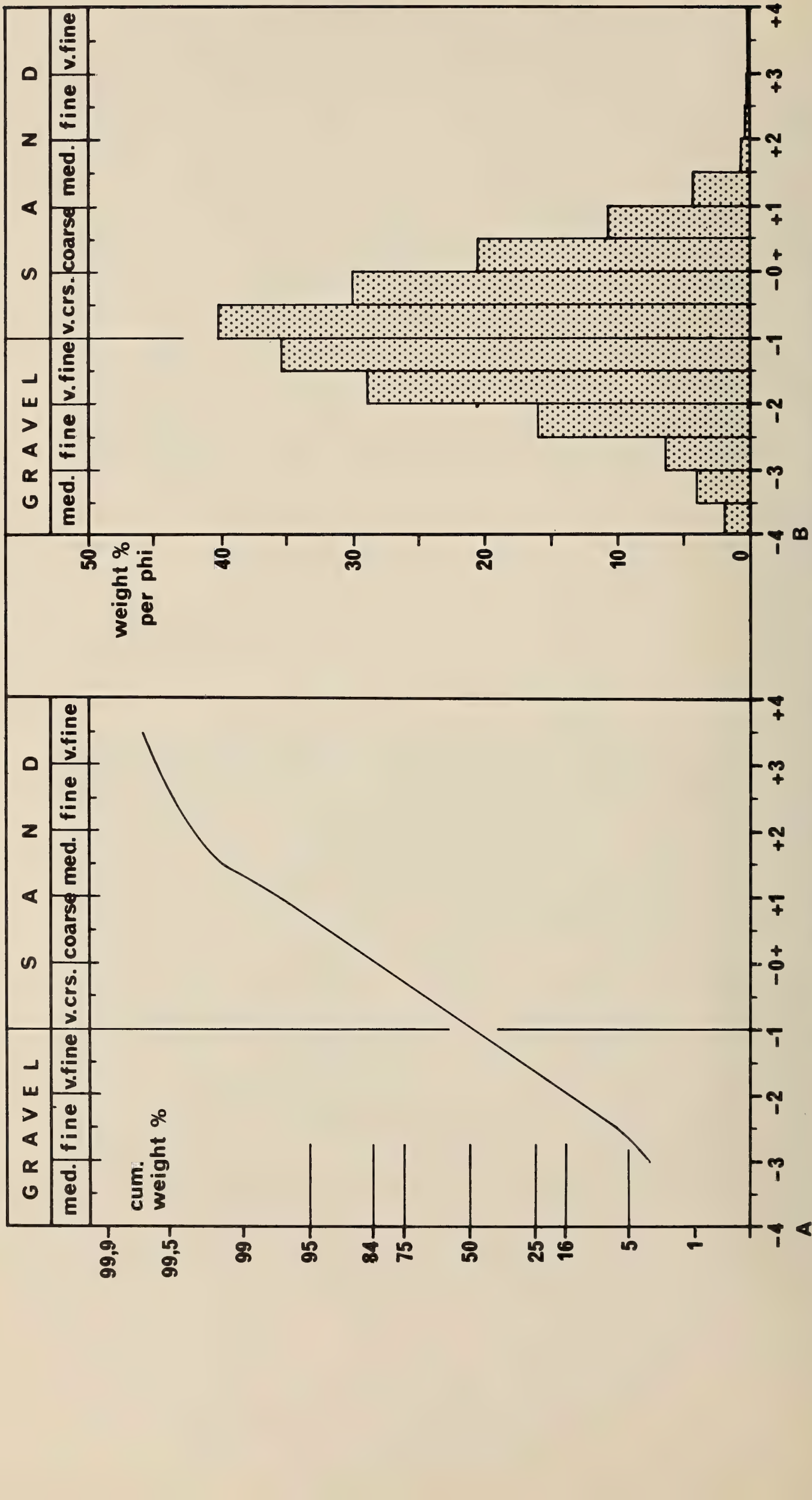


Fig. 6. A. Cumulative curve on probability paper. B. Frequency histogram at ½-phi intervals.

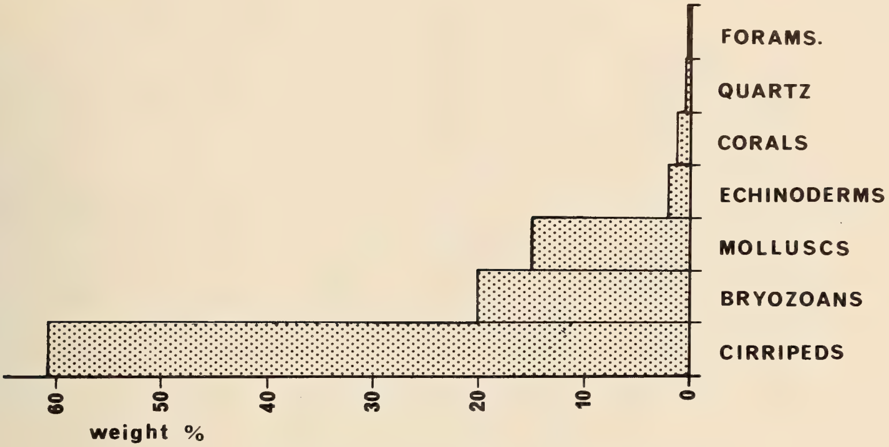


Fig. 7. Relative frequency of individual component groups.

the two deeper platforms to allow the same interpretation. However, they do show a striking coincidence with Pleistocene sea-levels discussed elsewhere in the literature (e.g. Emiliani 1955, 1966; Donn, Farrand & Ewing 1962; Broecker 1971; Shackleton & Opdyke 1973; Evans 1974). Furthermore, at similar levels beach deposits and extensive terraces have been recorded off the east and west coast of southern Africa on several occasions (Bremner 1973; Flemming 1975).

Having established the wave-cut origin of the upper platform, criteria have to be sought to establish whether this platform is being actively abraded today or whether we are dealing with a relict feature. As early as 1949 Berthoise suggested that marine abrasion is restricted to the upper few metres of the sea. From work carried out along the Pacific coast of the U.S.A., Longwell & Flint (1955) as well as Bradley (1958) reach the conclusion that submarine abrasion is restricted to the upper 10–12 m. Flemming (1965, 1968) presents geomorphic evidence for an abrasion base at —10 m and the author of this article has found sedimentological evidence in the Western Baltic which distinctly defines this limit at —13 m (Flemming & Wefer 1973). Recent underwater investigations in Saldanha Bay, South Africa, have revealed similar evidence at —15 m (Flemming, unpublished). In both cases side-scan sonar showed this to be a continuous feature. Hence, although the wave base, calculated roughly at half the wave length, may well reach down to 100 m or more, the above authors agree that submarine abrasion is restricted to the upper 10–15 m. The unexpected agreement of abrasion levels observed in extremely diverse marine environments in various parts of the world indeed suggests a common cause.

The hypothesis that the abrasion platform is essentially a function of the energy generated by the most frequently occurring waves would seem a plausible explanation. To test this hypothesis theoretically, the attenuation of orbital velocities with increasing water depth was calculated for a variety of waves,

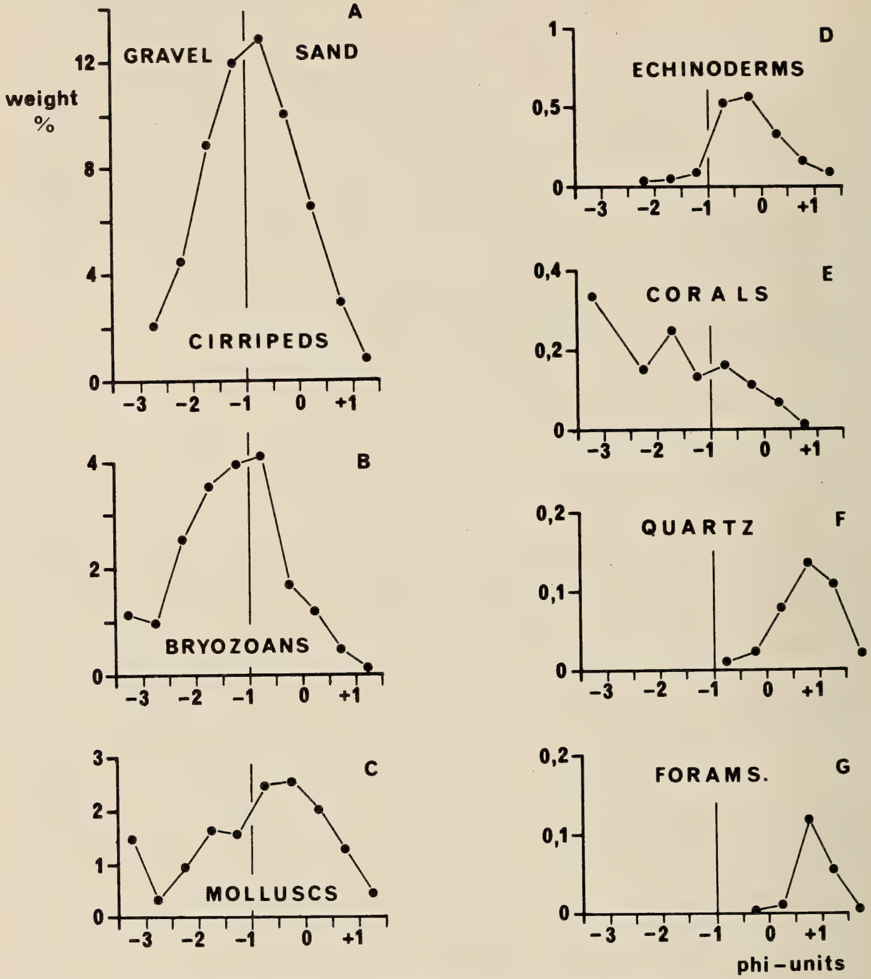


Fig. 8. Size distribution of individual component groups.

utilizing the method of Rankine (Zenkovich 1967). Figure 10 presents a theoretical velocity vs. depth diagram for deep water waves with periods between 5 and 15 seconds and heights from 1 to 10 metres. Not shown in the diagram are the various frequencies at which these individual waves occur since they might change from place to place. For South African waters frequencies for wave heights and zero-crossing periods were calculated for the depth ranges 0–15 m and > 15 m using data compiled by Darbyshire & Darbyshire (1964), Darbyshire & Pritchard (1966) and Shillington (1974). The 15 m division line was chosen because it demarcates the observed abrasion base in this area. Two threshold velocities were arbitrarily selected from the empirical data of Hjulström (1935), modified by Sundborg (1956), and modified by Allen (1965).

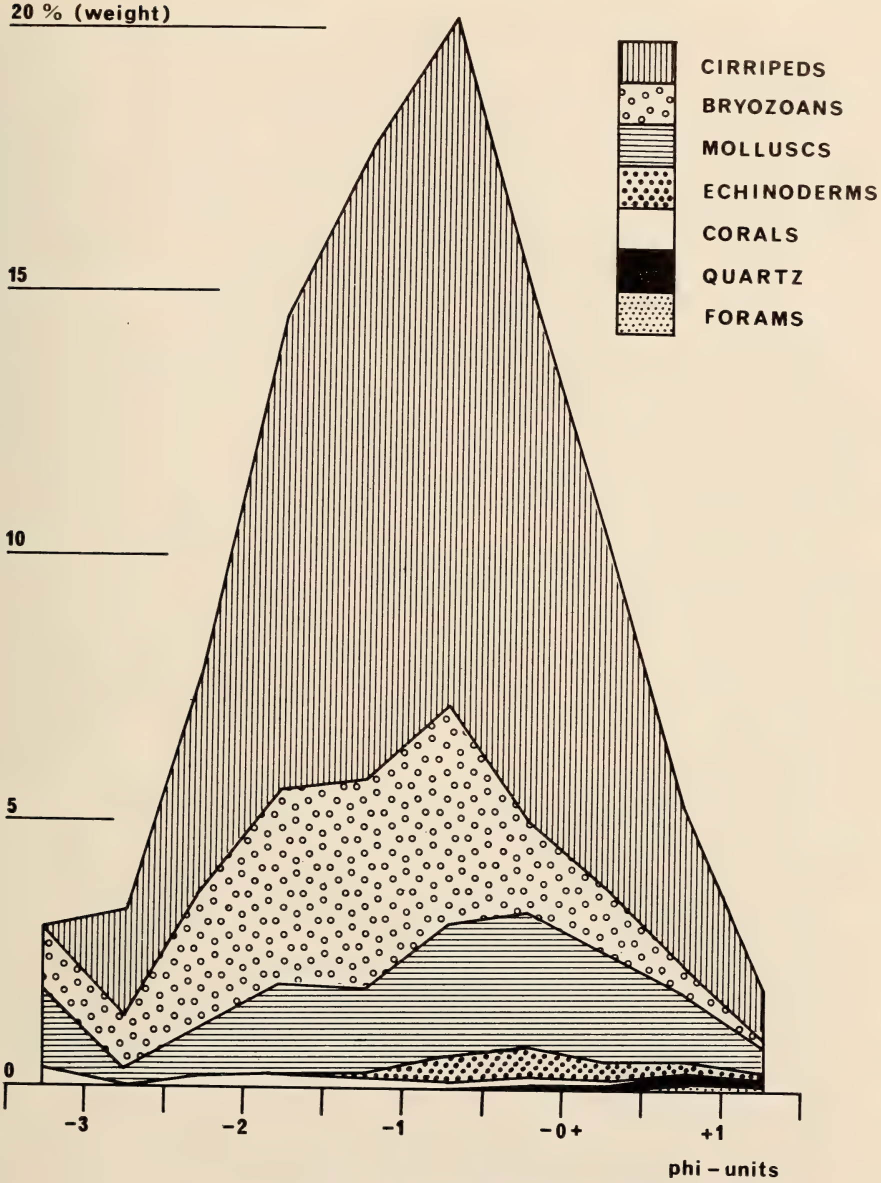
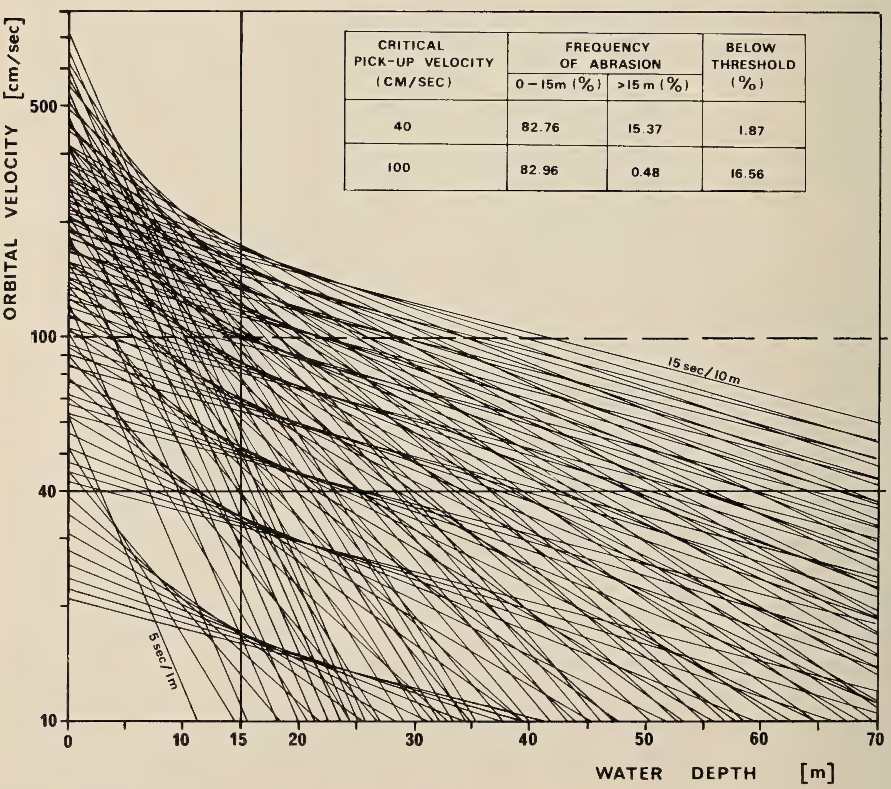


Fig. 9. Sediment components displayed in a composite frequency polygon.

The first, 40 cm/sec, would be sufficient to move residual sediments composed of coarse sands and fine gravels, a size range commonly encountered on abrasion platforms. The second, 100 cm/sec, was chosen following the assumption that higher velocities would move this sediment with increasing violence, thereby sharply increasing the abrasion rates.

The resulting figures, displayed in Figure 10 (inset), strongly support the suggested hypothesis. Velocities above 100 cm/sec are practically non-existent below 15 m and even the threshold velocity of 40 cm/sec occurs at a frequency of only 15 per cent below this depth. The conclusion that the boundary between abrasion and sedimentation reflects a delicate equilibrium maintained only by the constancy of the wave spectrum over a long period of time, seems justified. Furthermore, the evidence for very similar depth levels of abrasion bases reported from various parts of the world suggests that wave spectra are very similar on a global scale. A recent compilation of long-term wind and wave data on a world-wide scale by Davies (1972) indicates that this approach certainly points in the right direction. From the above considerations we can conclude that Rocky Bank cannot represent an active abrasion platform under the present hydrological regime. This is also reflected by the sediments of Rocky Bank. Quartz, which would certainly form a major sedimentary component if appreciable abrasion took place, contributes a mere 0,37 per cent to the total mass of the sediment (Fig. 9). Furthermore, all cobbles with diameters



CRITICAL PICK-UP VELOCITY (CM/SEC)	FREQUENCY OF ABRASION		BELOW THRESHOLD (%)
	0 – 15m (%)	>15 m (%)	
40	82.76	15.37	1.87
100	82.96	0.48	16.56

Fig. 10. Theoretical velocity vs. depth diagram of deep water waves with periods between 5 and 15 seconds and heights from 1 to 10 metres.
Inset: percentages of wave frequencies for 40 cm/sec and 100 cm/sec threshold velocities.

$>$ 10 cm are entirely coated by encrusting algae that show no sign of wear, indicating that pick-up velocities for this grain size are rarely if ever achieved. Yet they are very well rounded (Fig. 11).

To explain the wave-cut origin of Rocky Bank, a sea-level at least 20–25 m below the present must be assumed. Wright (1964) and Murray *et al.* (1970) have traced a submerged cliff at —20 m along parts of the South African west coast and ascribe this feature to the post-Pleistocene transgression. The previous Pleistocene event with sea-levels permitting abrasion at this depth dates between *c.* 110 000 and 80 000 B.P. (Shackleton & Opdyke 1973). However, it seems doubtful whether 70 000 years of sub-aerial erosion would have left intact the features discussed above. The platform could well have been pre-formed at that time but its present appearance would nevertheless be a modification due to the Flandrian transgression. To develop a pronounced abrasion platform the sea-level must have been reasonably stable for some time around —20 to —25 m or at least risen at a reduced rate. Inflection points in the rising sea-level curve have in fact been suggested by a number of authors at about 9 000 years B.P. (e.g. Mörner 1971). Whether 1 000–2 000 years would be sufficient to render a platform of this dimension, however, remains a matter of argument. Recent C^{14} dates from South Africa suggest that during the Würm I/II Interstadial the sea-level actually rose to *c.* — 25 m (Tankard, pers. comm. 1975) and not merely to — 50 m as suggested by Shackleton & Opdyke (1973). If this could be substantiated then the observed wave-cut platform (Fig. 12) would certainly be adequately explained.

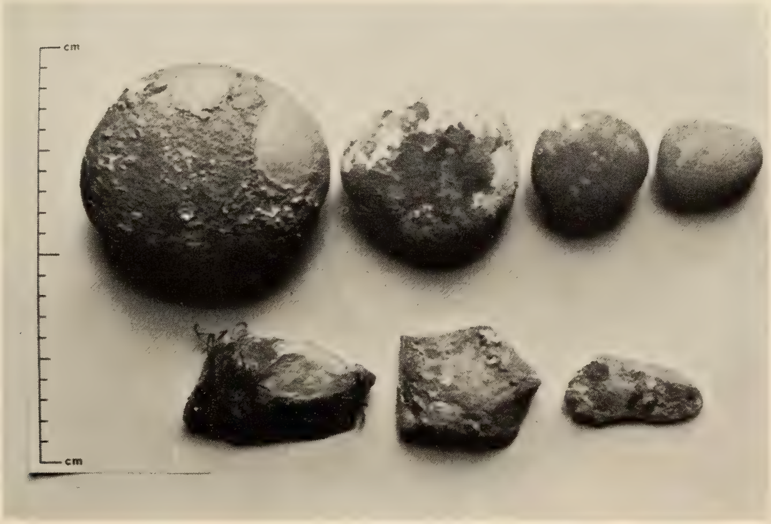


Fig. 11. Rock samples.
Top—well-rounded pebbles and cobbles.
Bottom—bedrock chips.

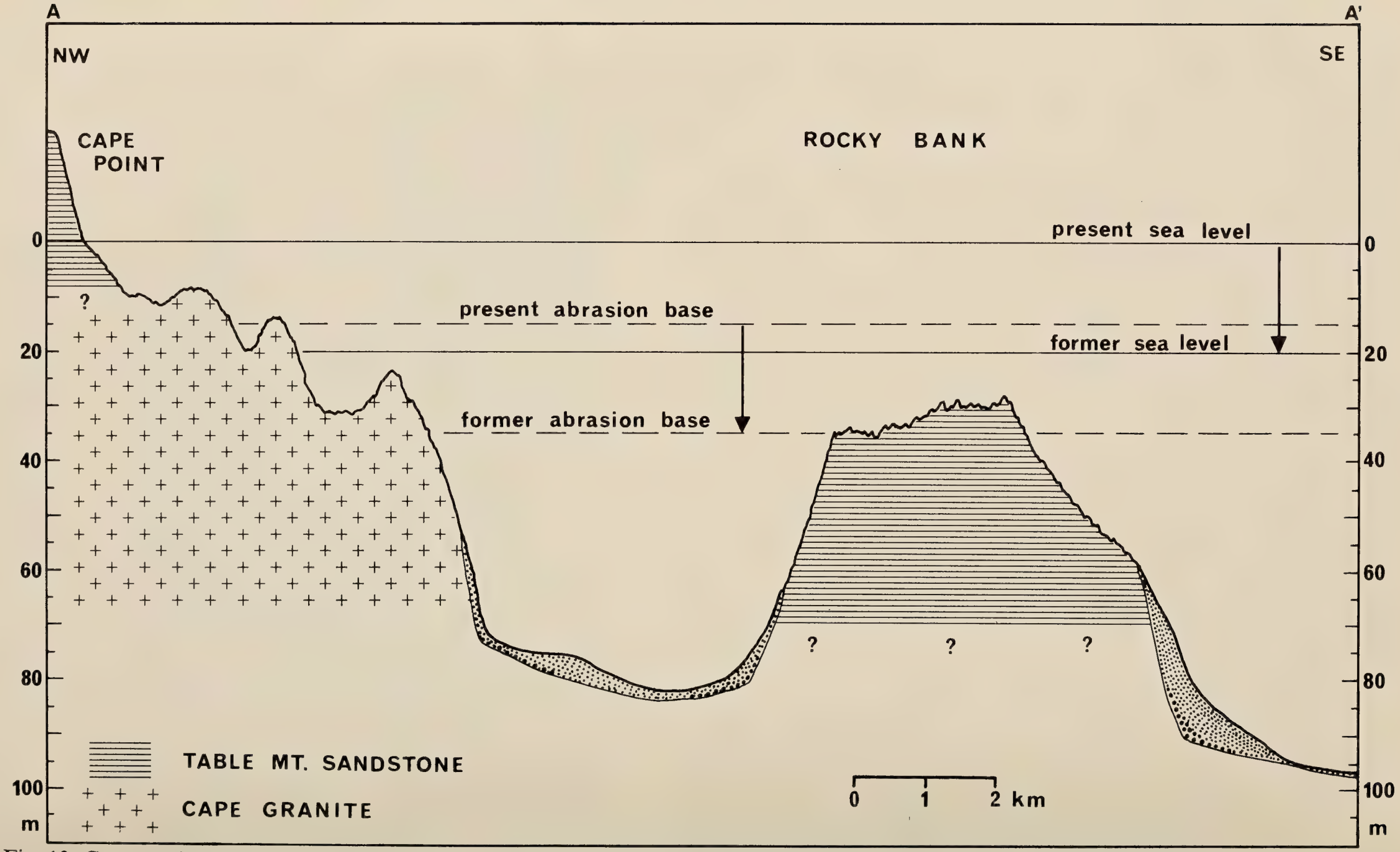


Fig. 12. Cross-section through Rocky Bank along Line A/A^1, showing the former sea-level at −20 m and the respective abrasion base at −35 m.

A final point in this discussion deals with the problem of inferring former sea-levels from raised marine deposits. First of all, raised beaches must be distinguished from raised terraces. A raised beach always allows the definition of the related sea-level, but it will not indicate whether it was stable or not. A raised terrace on the other hand always implies a relative stable sea-level but it does not automatically define the related sea-level unless it is known with certainty which part of the abrasion platform it represents. As we have seen, the sea-level can be anywhere up to 15 m above a wave-cut platform.

SUMMARY

An underwater investigation, carried out in 1973, revealed that Rocky Bank, a sandstone outcrop at the mouth of False Bay, South Africa, represents a wave-cut platform. This is demonstrated by the relatively large surface area taken up by the 35 m to 40 m depth contours as well as the loose cover by well-rounded pebbles, cobbles and boulders. The platform is dissected by numerous shallow gullies running parallel to the direction of the swell. They were probably eroded by wave action. The sediments are almost entirely of biogenic origin, indicating that submarine abrasion of the sandstone platform is virtually non-existent under present hydrological conditions.

This is further supported by the theoretical calculation of orbital velocities from various wave parameters. Wave frequencies in South African waters clearly demonstrate the concentration of wave energy in the upper 15 m of the water column. Similar depth levels of abrasion bases (10–15 m) reported from various parts of the world suggest that the constancy of wave spectra over long periods of time are similar on a global scale. The wave-cut platform is thought to be essentially a feature of the Flandrian transgression, although recent C^{14} dates would not exclude the possibility of a Würm I/II Interstadial event.

The problem of inferring former sea-levels from raised terraces is pointed out. It is essential that the position of the exposed terrace relative to its position on the former abrasion platform is known before a definite sea-level can be inferred.

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L'ÉVOLUTION A LA FIN DU PLÉISTOCÈNE ET A L'HOLOCÈNE DU LITTORAL ANGOLAIS DE LOBITO–BENGUELA ET MOSSAMEDES

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(Avec 7 figures et 1 tableau)

RÉSUMÉ

L'étude entreprise ici devra être considérée comme une mise à jour du travail effectué par les auteurs portugais sur les côtes de l'Angola.

On essayera de dégager les chronologies anciennes basées sur les séquences méditerranéennes et de les actualiser en les parallèlisant avec les séquences utilisées en Afrique de l'Ouest (Mauritanie).

Les arguments sédimentologiques permettent une reconstitution paléogéographique précise, et, plusiers mesures au C^{14} servent de base à la chronologie des lignes de rivage surélevées.

Les faunes et les microfaunes nous permettent pour chacun de ces niveaux de nous rendre compte que la température de l'océan semblait plus élevée que de nos jours, et ainsi d'émettre des hypothèses sur la pérennité du courant froid de Benguela au cours de l'époque envisagée.

ABSTRACT

THE EVOLUTION AT THE END OF THE PLEISTOCENE AND HOLOCENE OF THE ANGOLAN COAST OF LOBITO-BENGUELA AND MOSSAMEDES

The present study should be considered as a survey of research carried out by Portuguese workers on the Angolan coast.

An attempt is made to depart from former chronologies based upon Mediterranean sequences and to bring them up to date by comparing them with those used in West Africa (Mauritania).

Sedimentological evidence allows detailed reconstruction of the palaeogeography and several C^{14} assays form a framework for the chronology of the raised beaches.

In each level the fauna and the microfauna suggest that sea temperature was higher than it is today and thus allow the formulation of hypotheses concerning the permanance of the cold Benguela current during the period under discussion.

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INTRODUCTION

Notre étude considérera tout particulièrement les deux secteurs de Lobito–Benguela d'une part et de Mossamedes d'autre part, mais dans le cadre plus général de la côte atlantique.

Nos observations, en effet, ont pour objet l'examen de l'évolution eustatique au Pléistocène final et à l'Holocène sur la côte africaine sud atlantique et l'interprétation en particulier de la côte angolaise à la lumière des phénomènes des secteurs voisins.

Les études micropaléontologiques et sédimentologiques se sont souvent appuyées sur la connaissance des *facteurs actuels,* notre postulat à priori admettant dans cette région, une certaine chronicité des conditions physiques depuis au moins la fin du Pléistocène. Les modifications n'intervenant qu'à l'échelle d'une évolution progressive.

1. CADRE GÉOGRAPHIQUE ACTUEL

Le littoral angolais procède de différentes zones climatiques fonction de la latitude:

- —le secteur au nord de Luanda est régi par un climat tropical peu humide (type soudanien) que l'on retrouve à quelques nuances près sur la côte angolaise.
- —de Luanda à Mossamédès, des vents secs alizés interviennent et conditionnent un climat semi-aride de type sénégalien.
- —à la limite du Sud-Ouest Africain et de l'Angola, l'aridification s'intensifie, la température s'abaisse, un climat désertique de type saharien est en place.

La dynamique des eaux littorales est dirigée par le courant froid de Benguela orienté du Cap vers l'Equateur. Le courant a une influence directe sur la zonation climatique que nous venons de décrire, mais encore sur la température des eaux qui, sur une verticale donnée, présente des variations saisonnières de plus en plus contrastées en allant vers le Nord.

Pendant l'été austral, les eaux chaudes guinéennes peuvent descendre jusqu'à Luanda. Pendant l'hiver, les eaux froides et salées du courant de Benguela remontent jusqu'au Gabon et sont donc prépondérantes dans la zone considérée.

L'installation des eaux froides est synchrone de la mise en place de vents de terre qui poussent les eaux de surface vers le large, facilitant ainsi les arrivées d'eaux profondes, riches en matières nutritives.

On conçoit donc l'importance considérable de la dynamique de ce courant de Benguela quant à la composition de faunes benthiques et pélagiques de la plate-forme.

Des variations de la progression vers le Nord de ce courant, peuvent découler de très importants changements de population lors de l'histoire quaternaire récente.

Les vents côtiers dominants sont d'origine SW et déterminent une houle progressant vers le Nord. Comme pour les côtes congolaises, on observe de très fréquentes flèches littorales orientées du Sud au Nord. Les plus remarquables par leur extension sont celles de Baïa dos Tigres, de Porto Alexandre, et celles qui abritent les eaux du port de Lobito et surtout de Luanda où les bancs sableux servent de fondations à certaines installations portuaires.

Du point de vue morphologie, les affleurements tertiaires et secondaires généralement assez meubles, forment des falaises souvent érodées où l'escarpement est assez fréquent. Parfois, les couches basaltiques post-turoniennes couronnent les reliefs et forment cuestas. Les formations ont pu être aisément entaillées par l'érosion des mers quaternaires qui ont laissé des surfaces d'abrasion assez remarquablement étagées jusqu'à 145 m (Soares de Carvalho 1961*b*), celles de 20 m et 40 m étant assez réguliérement visibles.

2. CADRE TECTONIQUE ET GÉOLOGIQUE

Les deux bassins sédimentaires étudiées ici sont situés sur une côte quasi rectiligne de direction générale NNE–SSW depuis le 11° de latitude Sud jusqu'au 17° de latitude Sud soit entre Lobito et Port Alexandre sur près de 800 km.

Les deux unités sont séparées par un affleurement de socle précambrien au niveau du Cabo Santa Maria, nous nommerons celui du Nord bassin de Benguela–Lobito, et celui du Sud, bassin de Mossamédès.

Au nord du Précambrien de Cabo Santa Maria, les séries sédimentaires crétacés et cénozoïques affleurent avec un pendage de 20° vers le NW et forment de légères structures plissées dont les axes anticlinaux et synclinaux sont NE–SW, ces plissements sont accompagnés de failles de même direction ou de direction NS (Mascarenhas Neto 1960); ces failles ont joués durant le Miocène, et à des époques bien plus récentes car les auteurs portugais signalent le 'Pléistocène' sensu lato à des altitudes variant entre quelques mètres et plus de 150 m; ainsi Soares de Carvalho (1960) cite un conglomérat à *Arca senilis* L. et industrie paléolithique de facture acheuléenne au Sud de la Ponta de Sombreiro: 'a topo dos depositos tem cotas da ordem dos 155 metros.' Encore que ce dépôt très élevé doive sans doute être daté du Pléistocène (Clark 1963).

On peut donc penser à un système de flancs de synclinaux ou d'anticlinaux faillés en marches d'escaliers qui portent 'le Pléistocène sensu lato' à des altitudes aussi hautes; ce Pléistocène doit correspondre à un Tafaritien ou à la rigueur à un Aïoujien car des datations au C^{14} dans le région de Baïa Farta donnent des âges supérieurs ou égaux à 35 000 ans BP.

Au Sud du Cabo Santa Maria, les affleurements quaternaires existent dans la région de San Nicolau et dans celles de Mossamédès et Port Alexandre, la seule tectonique qui leur soit associée est un faillage presque Nord Sud bordant le socle. Cependant, nous relevons le fait que des faunes à Ostréïdes, *Arca senilis* L. et *Anomia ephippium* L. aient été trouvées dans le conglomérat de

Chalunga à des altitudes comprises entre 170 m et 180 m (Soares de Carvalho 1961*b*: 156).

Dans la région de Port Alexandre un beach rock a été trouvé à une altitude comprise entre 40 m et 50 m et contient des faunes à *Ostrea* sp. L. et *Rotula* cf. *augusti* Klein, cet affleurement pourrait correspondre à une terrasse 'Tyrhénienne' au sens que l'emploient les auteurs portugais c'est-à-dire à l'Aïoujien, ou, à un Inchirien.

3. ASPECTS SÉDIMENTOLOGIQUES DES DÉPÔTS DES TERRASSES INFÉRIEURES A 20 MÈTRES

Les analyses ont portés successivement sur les plages actuelles et celles plus anciennes surélevées et en vis à vis. Comme indiqué en introduction, les conditions physiques de sédimentation seront mises en parallèle et supposées peu variables.

Morphologie

La quasi totalité des grains de quartz observés aussi bien, dans les plages actuelles (jusqu'à Luanda) que sur les terrasses de Lobito–Benguela et Mossamédès sont de type non usé et l'émoussé façonné par l'abrasion marine y est à peine décelable.

Egalement les caries d'origine pédogénétique ne sont pas remarquées, même à Luanda pourtant sous climat sub-tropical. Ces observations conduisent à deux interprétations d'ailleurs complémentaires:

—La permanence d'un climat à dominante aride depuis le Pléistocène permet une érosion importante par thermoclastisme dont G. Soares de Carvalho souligne d'ailleurs le modelé et les figures d'érosion caractéristiques. Un tel climat a pu présenter quelques variantes, mais son caractère essentiel est demeuré assez constant.

—Le transport de la roche-mère à la bordure du bassin a été bref: les relais détritiques sont courts et peu fréquents. A partir d'une érosion mécanique toujours active, l'épirogénie de la côte et le débit irrégulier des fleuves ont permis une sédimentation importante des sables. G. Soares de Carvalho avait déjà souligné la réunion de conditions favorables à une accumulation de considérables réserves détritiques, notamment lors de la régression préflandrienne.

En fait, il semble que l'accumulation rapide soit intervenue aussi bien avant, qu'après cette régression.

Minéralogie

La plupart des plages de l'Angola sont caractérisés par la dominance des minéraux verts (épidote, hornblende et parfois hypersthéne et olivine). Les pourcentages relatifs des deux espèces cardinales (épidote et hornblende) permettent d'établir des divisions locales sur lesquelles nous n'insisterons pas ici.

	AGES ABSOLUS BP x 1000	TERMINOLOGIE	CHRONOLOGIE DEFINIE PAR LES AUTEURS PORTUGAIS	AGES ABSOLUS BP x 1000	CHRONOLOGIE DE L'AFRIQUE DE L'OUEST	CHRONOLOGIE PROPOSEE	
HOLOCENE		FLANDRIEN	ACTUEL TRANSGRESSIF	2	ACTUEL	Praïa des Conchas	AN37: Moderne
			Phase Regressive Finale	4	*TAFOLIEN*		
			TRANSGRESSION	6	NOUAKCHOTTIEN	Praïa des Conchas	AN14 : 3430± 100 AN15 AN16 : 3040± 100 AN35,36,38 AN39,40
	10		*Regression Grimaldienne*	9	*TCHADIEN*		
PLEISTOCENE		*NEOWURM*		25	*OGOLIEN*		
	30	TYRRHENIEN 2	OULJIEN	40	INCHIRIEN	Benguela Lobito Port Alexandre	AN22 ≫ 35000 AN27 AN46 ≫ 35000 AN47,48,49,50,51,52 AN53,54,56,57 AN42
	50 70	*EOWURM*	*Regression Pré Ouljienne*	70	*AGUERGUERIEN*		
	100	TYRRHENIEN 1	TYRRHENIEN	100	AIOUJIEN	Mossamedes	AN30,31,32,33,34
		RISS	*Anté Tyrrhenien* *Sables de Miramar* *et Conglomerat de Chalunga*	150	*AKCHARIEN*		
					TAFARITIEN		

Table 1. Comparaison des chronologies variées utilisées en Angoıa.

Dans les plages actuelles des poids exceptionnels de minéraux lourds sont obtenus: les pourcentages par rapport à la fraction légère atteignent 20 à 30 et même plus de 50 pour cent dans plusiers cas (fractions fines). Par comparaison, les sables des plages surélevées jusqu'à 20 mètres sont moins riches (1 à 10 pour cent). *Ce sera un des rares aspects permettant une différenciation entre les deux séries de plages*, les plus anciennes sont plus riches en débris coquilliers ce qui abaisse d'autant le poids relatif des espèces lourdes. De plus, comme les minéraux verts sont extrêmement altérables, peut-être qu'un temps de sédimentation et une diagénèse plus longs et un climat plus contrasté ont abouti à l'élimination de certains d'entre eux.

L'origine de ces minéraux verts est très voisine de la côte: le très vaste massif granitique précambrien longe le littoral depuis Mossamédès jusqu'à Novo Redondo. Ce massif présente de fréquentes enclaves de dolérites pigeonitiques. Enfin sur la falaise marine affleure une couche volcanique souvent basaltique qui est interstratifiée entre le Turonien et le Campanien; des petits cristaux d'olivine sont parfois décrits dans les basaltes (Armado) par G. Soares de Carvalho. Les matériaux d'érosion se concentrent localement en fonction de l'apport irrégulier des oueds côtiers.

Les plages constituent une vaste province pétrographique allant vers le Nord, au moins jusqu'à Luanda malgré l'éloignement du massif éruptif; les apports fluviaux et surtout l'importante dérive littorale rendent compte de cette unité dont la limite nord ne peut être précisée; en tout état de cause, les plages du Zaïre, du Cabinda et du Congo ont des sables très différents par l'émoussé des grains et les cortèges minéralogiques. Vers le Sud, la limite est située au milieu de la Baie de Mossamédès dont les plages septentrionales sont très riches en minéraux verts alors que celles du Sud (Praïa Amelia) voient apparaître deux minéraux de métamorphisme peu fréquents jusqu'alors: le grenat et l'andalousite. Cette limite correspond à l'embouchure d'un oued important, le Rio Bero qui descend des reliefs granitiques, traverse les porphyres, et dont les alluvions sont ensuite entrainées vers le Nord de la Baie.

Il est très remarquable de constater que cette division de la Baie au niveau des plages actuelles se retrouve très fidèlement au niveau des plages anciennes surélévées jusqu'à 15 mètres. On démontre ainsi *une pérennité pendant la période correspondante des vents dominants qui orientent la dérive littorale vers le Nord et de l'importance des apports du Rio Bero à travers d'éventuelles petites fluctuations climatiques.*

Les terrasses de Lobito et de Benguela présentent des dépôts eux aussi, minéralogiquement semblables à ceux des plages actuelles sous-jacentes même quand une rubéfaction est intervenue (AN 51).

Les minéraux accessoires soulignent souvent cette distribution générale:

—la staurotide souligne l'importance du métamorphisme au Sud du Rio Bero, mais encore à Luanda éloignée des apports directs du massif éruptif. Il en est de même du disthène.

—la tourmaline, le zircon et le rutile sont aussi plus fréquents à Luanda et au Sud du Mossamédès. Leurs teneurs ne s'élèvent pas dans les dépôts anciens et n'indiquent pas un vieillissement du cortège.

L'olivine est présenté parfois dans le secteur Benguela–Lobito tant sur les plages actuelles que fossiles; elle semble procéder des intrusions basaltiques crétacées de la côte.

L'hypersthène n'accompagne que rarement les amphiboles et les épidotes sauf dans la Baie de Mossamédès (5 à 10 pour cent en fraction moyenne). L'augite, très rare, lui semble associée.

La barytine est trouvée dans la terrasse de 20 mètres de Benguela (AN 54, 55) où elle est remaniée à partir des géodes de séries calcaires de l'Albien inférieur. Ce minéral fragile a été peu dispersé.

Enfin, dans les minéraux opaques où les altérations ferrugineuses sont absentes, signalons des ilménites irrégulièrement concentrées en fonction des oueds locaux. Une forte teneur en ilménite correspond à une forte teneur générale en grains lourds.

Les carbonates

Les plages actuelles, mises à part les bandes localisées où les coquilles sont concentrées, sont relativement peu carbonatées pas plus de 5 pour cent. sauf exception.

Les plages anciennes sont beaucoup plus riches: toujours plus de 30 pour cent. Donc en dépit des analogies physiques constatées plus haut dans les deux séries de dépôt, *un certain refroidissement des eaux est envisageable en allant vers l'actuel.*

Les montages de fraction lourde ont permis d'observer l'aragonite dans la plupart des sédiments. Il en est de même pour l'ankérite qui n'existait pas sur les côtes du Congo: un des niveaux de terrasses (AN 46) près de Lobito est très riche en ankérite. La précipitation des carbonates authigènes (calcites le plus souvent) est nette dans beaucoup de niveaux de terrasses de Lobito à Mossamédès où les silts quartzeux sont cimentés en petites boules friables (AN 40, AN 46, AN 52, AN 53, AN 54, AN 57); certains quartz sont même encroûtés par les carbonates, phénomène peut-être diagénétique que l'on ne voit pas sur les plages modernes.

Les carbonates d'origine organique sont prépondérants: ce sont des débris de test de mollusques sous forme de lamelles corrodées et de petite taille, de tubes de ver, mais aussi des ostracodes et des foraminifères assez fréquents.

Des plaques minces ont été effectuées dans les gros tests de mollusques conservés. Aucune recristallisation de la calcite n'est observée dans les coquilles des niveaux inférieurs à 20 m qui nous intéressent surtout ici. Par contre, quelques tests récoltés vers 40 m (niveaux tyrrhéniens à Strombes de G. Soares de Carvalho) laissent voir quelques minéralisations secondaires qui pourrait fausser des mesures radiochronologiques. Par contre, les mesures au C^{14} des témoins de bas niveaux ne semblent présenter aucune source de rajeunissement.

En résumé, quels arguments paléogéographiques relatifs aux plages surélevées, peut-on retirer de cette esquisse sédimentologique?

1. Les études morphoscopiques et minéralogiques se rejoignent dans l'essentiel de leur conclusion: les apports sédimentaires ont été rapides, actifs car les quartz sont frais et les minéraux fragiles surabondants, les oueds compétents étaient les mêmes qu'aujourd'hui et la dérive littorale de même orientation et de même efficacité.

2. Un climat de type aride a controlé la sédimentation et a permis l'érosion caractéristique, les apports alluviaux irréguliers et locaux et une précipitation de certains carbonates authigènes pendant la diagénèse. Une légère altération a pu se traduire par l'élimination chimique de quelques minéraux fragiles présents dans le sable actuel.

3. L'abondance de tests calcaires grossiers par rapport à la plage moderne présume, avant l'inventaire faunistique détaillée de conditions écologiques favorables lors de périodes où le courant de Benguela était moins présent qu'aujourd'hui. Cette limite variable de l'influence du courant de Benguela ayant d'évidentes conséquences climatiques et donc géodynamiques comme nous l'avons remarqué en (2).

4. ETUDE PALÉONTOLOGIQUE ET MICROPALÉONTOLOGIQUE

Nous décrirons tout d'abord les faunes observées et leurs habitats dans la région de Mossamédès puis dans celle de Benguela–Lobito.

RÉGION DE MOSSAMÉDÈS

Sur une côte NS, la Baie de Mossamédès est une échancrure semicirculaire ouverte à l'Ouest et fermée par deux caps, la Ponta de Giraul au Nord et la Ponta de Noronha au Sud.

Les terrasses hautes

Les sédiments les plus anciens que nous y trouverons ont été décrits par les auteurs portugais (Soares de Carvalho 1961*b*) et les auteurs belges (Dartevelle 1952) qui avaient défini une terrasse marine haute contenant des *Strombus bubonius* Lamk., *Arca senilis* L., *Thais haemastoma* L., et des restes d'échinodermes sous forme de digitations de *Rotulinae*; on y a même trouvé (Faber 1926) des restes de madréporaires (AN 42).

Nous avons observé ces affleurements sur les escarpements de Torre de Tombo au Sud de la ville et sur les falaises surplombant la Praïa Amelia. On y trouve la faune décrite plus haut accompagnée de restes d'ostréides et des gastéropodes tels que *Bulla* aff. *adansoni* Philippi et *Pugilina* aff. *morio* L. (AN 32, 33, 34).

G. Soares de Carvalho attribue à ces coquilles un âge Tyrrhénien auquel nous donnerons le nom d'Aïoujien en liaison avec la nouvelle stratigraphie de Quaternaire définie au Sénégal et en Mauritanie (Elouard & Faure 1967).

Nous avons vu plus haut que près de Port Alexandre, donc 80 km au Sud un affleurement avec un beach rock aréno-calcaire contenait une faune à *Ostrea* sp., *Ostrea* aff. *folium* L., des fragments de madréporaires et des digitations d'échinodermes qui pourrait appartenir à *Radiorotula orbiculus* L. et à *Rotula augusti* Klein, nous avons hésité sur l'âge de ce dépôt, mais vu l'état de conservation des animaux, il semble inchirien.

Les terrasses basses

La région de Mossamédès nous fournira encore de beaux affleurements, vers Baïa des Pipas, sur la route y conduisant ou sur le plateau calcaire de la Ponta de Giraul et de Praïa des Conchas. Mais nous sommes là en présence d'affleurements beaucoup plus récents et qui ont pu être datés.

Au Sud W de la ville à Praïa Amelia, au-dessous de la falaise portant l'Aïoujien et à +2 m, nous trouvons une plage dont la faune a été datée AN 10/2 (GIF 3220) 1620 ± 80 BP, mais cet âge est certainement trop faible car nous pensons cet affleurement Nouakchottien, les géologues portugais (Soares de Carvalho) lui donnaient l'âge Ouljien, cet âge Ouljien englobant le Nouakchottien et l'Inchirien.

A la Ponta do Giraul, Davies (1959) signale un stade Ouljien (Plage V) et un stade Monastirien (Plage IV) daté par un outillage Acheuléen ancien (30 m).

Le site de Praïa des Conchas est supporté par un entablement calcaire à pendage faible vers le NW et sa surface est parsemée de débris coquilliers, on y a même trouvé des fragments d'os de cétacés (5 m).

Nous sommes en présence de trois plages échelonnées suivant leurs altitudes.

A l'Est du plateau, une faune typique dont l'état d'usure fait penser à celle des

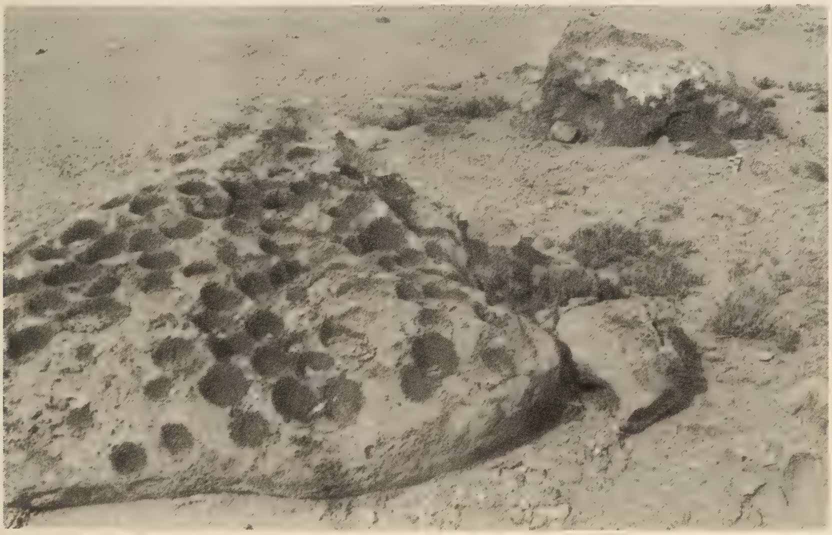

Fig. 1. Praïa des Conchas, Plage nouakchottiene (5 m) montrant des rochers corrodés par des Echinides (l'echelle mesure 25 cm).

falaises de Praïa Amelia donc à un Aïoujien, puis en descendant en altitude des *Strombus bubonius* Lamk. épais, avec *Thais haemastoma* L. d'âge inchirien car non encroûtés commes plus haut et, en bordure de falaise vers 3 à 5 m des rochers corrodés par des oursins au pied desquels se trouvent les débris coquilliers de la 'plage à *Vermetus* ouljienne' de Soares de Carvalho (1961*b*).

Là, des datations au C^{14} ont donné sur ces faunes des âges de 3420 ± 100 BP (AN 14, GIF 2945) et 3040 ± 100 BP (AN 16, GIF 2946), c'est-à-dire Nouakchottien pour des cotes respectives de +5 et +3 m.

L'échantillon AN 36 prélevé sur le même gisement contient la faune suivante:

Patella granularis Krauss, *Conus* aff. *ventricosus* Gmelin, *Thais haemastoma* L., *Cantharus viverratus* Kiener, *Nerita* sp. L., *Ostrea folium* L., *Vermetus adansoni* Daudin.

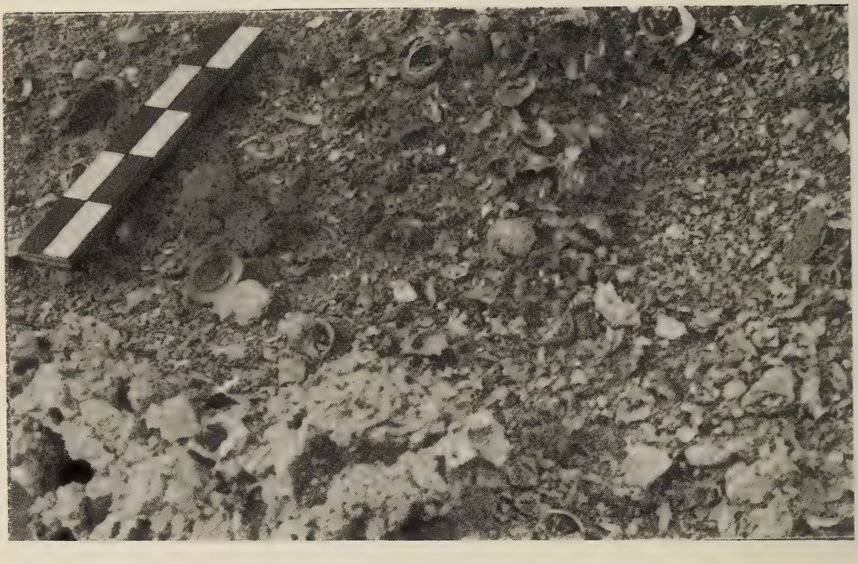

Fig. 2. Praïa des Conchas, dépôts de la plage nouakchottienne (3 à 5 m) à faune de gastéropodes *Patella granularis*, *Thais haemastoma*, et des ostréïdes (Echelle 25 cm).

En se rapprochant de la ligne de rivage actuelle et se mélangeant avec elle, nous trouverons une plage appelée 'plage à *Perna perna* L.' dont l'âge est Post Nouakchottien à actuel; on y trouve une faune à cirripèdes, à gastéropodes:

Patella granularis L., *Fissurella* sp. Brug., *Thais haemastoma* L., *Monodonta sagittifera* Lamk., *Calyptrea trochiformis* Gmelin, *Opalia crenata* L., *Cantharus viverratus* Kiener, et à lamellibranches *Perna perna* L.

Sur la route conduisant à Baïa des Pipas, nous trouvons un très riche affleurement dans des sables argileux (AN 39/40) (15 m) auquel nous donnerons

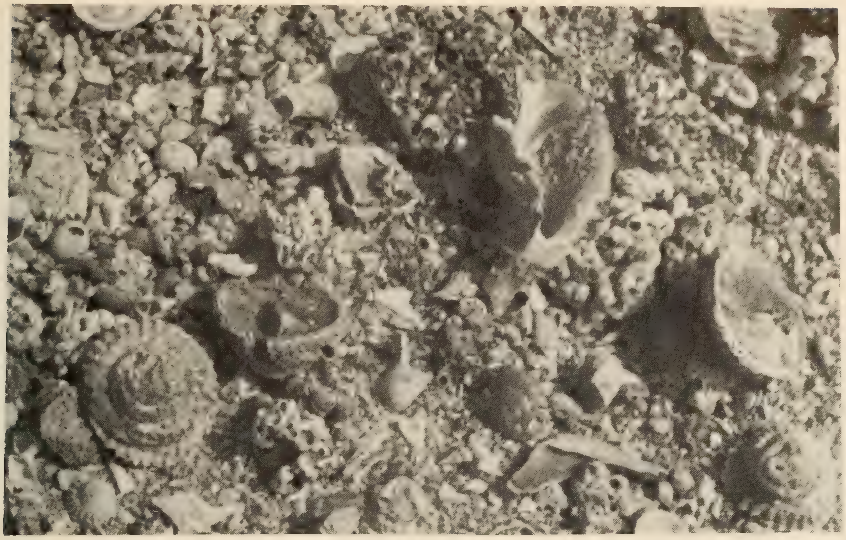

Fig. 3. Plage nouakchottienne à *Ostrea folium*, *Calyptrea chinensis*, *Thais haemastoma* (3 à 5 m) (½ de la grandeur naturelle).

un âge Nouakchottien contenant une faune très bien conservée de lamellibranches et de gastéropodes:

Spisula nivea Gmelin, *Mactra largillierti* Philippi, *Cardium ringens* Gmelin, *Solen marginatus* Pennant, *Natica* aff. *collaria* Lamk., *Natica collaria* Lamk., *Terebra senegalensis* Lamk., *Mesalia mesal.*

D'autres espéces sont en cours de détermination; de même ce sédiment a fourni une microfaune de foraminifères et d'ostracodes assez abondante:

Nonion asterizans Fichtel et Moll, *Florilus boueanus* Brady, *Elphidium crispum* L., *Elphidium complanatum* d'Orb., *Ammonia beccarii* L., *Quinqueloculina disparilis* d'Orb., *Quinqueloculina lamarckiana* d'Orb., *Eponides* sp. Montfort, *Eponides repandus* Fichtel et Moll, *Bolivina spathulata* Williamson, *Globigerina* aff. *bulloides* d'Orb.

Cette plage semble montrer un milieu infra littoral à apport d'eau douce de manière intermittente, et la faune que l'on trouve correspond bien à un Nouakchottien typique tel qu'il est décrit en Afrique de l'Ouest (Elouard 1968). Ainsi la présence de plages présentant des faunes identiques de manière symétrique par rapport à l'Equateur, Dakar 15° Nord, et Mossamédès 15° Sud, semblerait montrer l'existence d'une sédimentation et de conditions biologiques constantes au cours du Quaternaire sur les côtes d'Afrique. Cependant, se pose le problème de la présence au Sud de l'Equateur du courant froid de Benguela dont l'existence au Quaternaire ancien peut être discutée.

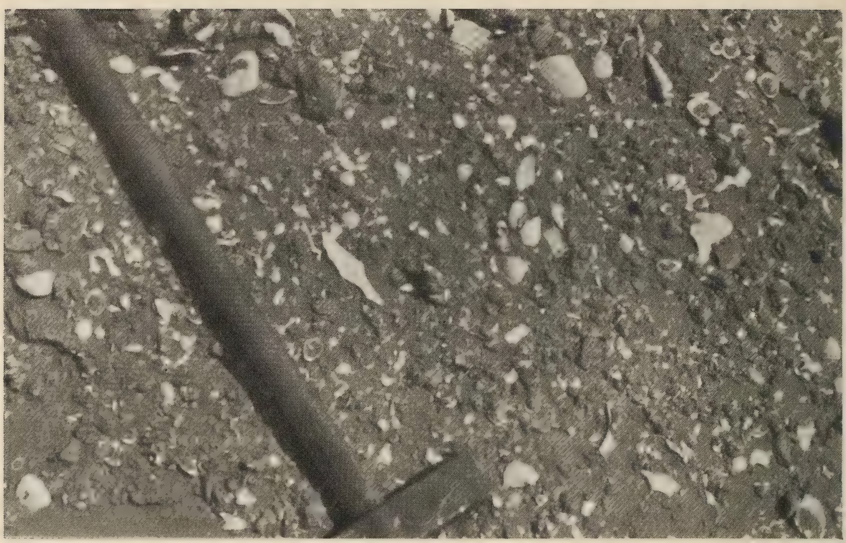

Fig. 4. Route de Baïa des Pipas (15 m), faune littorale nouakchottienne milieu infra-littoral de fond de baie (le marteau mesure 45 cm).

REGION DE LOBITO–BENGUELA

Dans cette région la succession des plages fossiles sera moins bien définie que dans la région précédente, on retrouvera la plage aïoujienne 'Tyrrhénienne' à 120 m (AN 43) sous forme d'un conglomérat concrétionné de graviers et de coquilles indéterminables à l'Est du phare de Lobito.

Par contre nous n'avons pas rencontré les affleurements signalés par Soares de Carvalho (1960) et Mascarenhas Neto (1960) aux alentours de la Ponta de Sombreiro.

Ensuite aux côtes d'altitude comprises entre 8 et 20 m trouvera souvent des affleurements à faunes diverses, auxquels nous donnerons un âge constant inchirien AN 46 (GIF 3232) ⩾ 35 000.

A la Ponta das Vacas, Davies (1959) signale trois terrasses entre 0 et 25 m, la plus récente qu'il date du Flandrien (Plage VI) contiendrait un outillage d'Age Sangoen récent, et est précédé par deux plages plus anciennes, une plage d'âge Ouljien (Plage V) et une autre d'âge Monastirien (Plage IV).

Dans les alentours immédiats de Lobito au Bairro de Santa Cruz au-dessous de sables très fins certainement ogoliens, nous trouvons des fragments coquilliers d'huîtres et de *Spisula nivea* Gmelin, et de Mactridées (8 à 10 m).

Puis dans la région de Catumbela, une sablière montre deux passées à *Arca senilis* L., *Chlamys varius* L., *Glycimeris* sp. da Costa et *Ostrea* sp. L. séparées par des sables plus ou moins rubefiés, suivant la succession suivante de haut en bas:

a: Sable ocre argileux fin, 3,00 m
b: Passée à *Arca senilis* L. (AN 46 ⩾ 35 000) 0,50 m

c: Sable ocre non argileux, 1,00 m
d: Passée à *Arca senilis* L., *Ostrea* sp., *Glycimeris* sp. da Costa, et *Chlamys varius* L. (AN 47, 48, 49), 0,50 m
e: Passée de sable grossier blanc non argileux, 1,00 m

C'est-à-dire un Ogolien ocre dunaire régressif recouvrant un Inchirien à *Arca senilis* L. qui présente deux épisodes, l'épisode supérieur étant plus lagunaire que l'inférieur. Cette hypothèse se confirme au SE de la ville de Benguela où l'on trouve une passée d'âge inchirien présentant une faune à *Arca senilis* L., *Pugilina morio* L. et *Ostrea* sp. L. prises en masse avec des sédiments de type lagunaire franc à gypse (AN 54).

La passée supérieure de l'Inchirien contient suivant les affleurements des coquilles de *Tympanotonus fuscatus* L.

La microfaune de la passée inchirien à *Arca senilis* L. est assez réduite et contient des animaux de faciès saumâtre tel *Ammonia beccarii* L., assez abondante, et *Reophax* sp. Montfort.

La microfaune de l'affleurement AN 54 est cependant plus riche en espèces: *Lenticulina iota* Cushman, *Lenticulina* aff. *calcar* L., *Bulimina inflata* Sequenza, *Bulimina striata* d'Orb., *Nonionella* sp. Cushman, *Elphidium incertum* Williamson, *Ammonia beccarii* L., *Eponides* sp. Montfort, *Bolivinoides* sp. Cushman, *Globigerina* aff. *bulloides* d'Orb.

Entre les deux gisements existe un affleurement (AN 53) dont la faune semble moins lagunaire et contenant:

Cardium ringens Gmelin, *Mactra largillierti* Philippi, *Natica* sp. Scopoli, *Mesalia mesal.*

La microfaune est composée de nombreux ostracodes et de foraminifères parmi lesquels:

Nonion asterizans Fichtel et Moll, *Nonionella atlantica* Cushman, *Ammonia beccarii* L., *Globigerina* aff. *bulloides* d'Orb.

A l'Est de ces affleurements, aux alentours du terrain d'aviation de Benguela une plage surélevée (20 à 25 m) montre *Ostrea* sp., *Arca senilis* L., *Cardium ringens* Gmelin, *Conus pulcher* Lightfoot, ces animaux étant très faiblement recristallisés.

Plus au Sud, vers le petit ville de Baïa Farta, les affleurements sont portés en altitude par une néotectonique cassante, on trouve deux affleurements inchiriens, un situé à 2 ou 3 m (AN 22) (GIF 2947) $\geqslant$ 35 000 ans à *Arca senilis* L., *Glycimeris* sp. da Costa, *Mactra largillierti* Philippi, et à 2 km de là, mais 20 m au-dessous un affleurement (AN 56) dont l'altération est de même aspect contenant:

Ostrea folium L., *Arca senilis* L., *Smaragdia viridis* L., *Tympanotonus fuscatus* L.

Près de Baïa Farta, à 80 m d'altitude, O. Davies (1959) signale une passée graveleuse qui pourrait être une plage intermédiaire entre les bas niveaux de la Porta das Vacas et les hauts niveaux de la Ponta do Sombreiro.

Le dernier affleurement que nous verrons sera peuplé essentiellement

Figs 5–6. Côte de Baïa Azul (près de Baïa Farta secteur de Benguela). Accumulation d'*Arca sensilis* L. et de *Tympanotonus fuscatus* L. et *Tympanotonus fuscatus* var. *radula* (15 m). Cette accumulation est certainement d'âge inchirien (¼ de la grandeur naturelle).

d'*Arca senilis* L. et de *Tympanotonus fuscatus* L., la microfaune à *Ammonia beccarii* L. et *Ammonia beccarii* L. var. *tepida*, *Quinqueloculina* sp. d'Orb. et de nombreux ostracodes à test lisse peut montrer un milieu à début de dessalure; quant à son âge, nous ne pouvons pas le définir exactement comme inchirien ou nouakchottien (AN 57 BAIA FARTA + 12 m).

La côte de la région de Lobito à Benguela, semble donc ne montrer que des affleurements inchiriens, peut-être des dragages effectués dans la baie de Benguela permettraient de démontrer la présence d'un Nouakchottien.

En résumé, nous avons donc vu entre Mossamédès et Lobito une concordance entre les faunes. Le Tyrrhénien–Aïoujien et l'Inchirien sont toujours caractérisés par les mêmes animaux du Sud au Nord.

Les dépôts aïoujiens appartiennent souvent à des facies littoraux de milieux chauds de fond de baie, mais sans apport d'eau douce, alors que les dépôts inchiriens semblent caractérisés par des animaux à tendance lagunaire *Arca senilis* L., *Tympanotonus fuscatus* L., seul l'Inchirien de Port Alexandre, montre des échinides et des madréporaires.

Quant au Nouakchottien, dans la région de Mossamédès où nous l'observons, nous lui verrons deux faciès:

—Un faciès infralittoral vaseux de fond de baie calme, à apports intermittents d'eau douce (AN 39/40).

—Un faciès littoral battu avec des rochers perforés par les échinides, des patelles et des huîtres (AN 38/36).

CONCLUSIONS

L'étagement des diverses lignes de rivages surélevées observées sur les côtes d'Angola est à peu près constant; cependant, il est à noter que les niveaux les plus récents, Nouakchottien et Inchirien, disparaissent de l'affleurement en allant vers le Nord.

L'Inchirien trouvé à Port Alexandre vers 50 m, existera sous un autre faciès entre Baïa Farta et Lobito à des altitudes plus basses (+15, +25 m).

Quant au Nouakchottien, il n'existera plus au niveau du secteur de Lobito–Benguela.

Vers Luanda, Ambriz, seules affleureront les plages aïoujiennes, puis au-delà du fleuve Congo, il n'existera plus que quelques plages holocènes qui disparaissent vers le Nord.

Les témoins de niveaux transgressifs trouvés au Nord du fleuve Congo présentant une faune assez bien conservé, l'ont été dans des carottages ou dans des dragages du plateau et du littoral congologabonais.

Dans les carottages de géotechnique effectués dans le port de Pointe-Noire, certaines passées entre —7 et —8 m ont montré des faunes de mactridés et d'ostréïdes, semblant être donc Nouakchottien, dont l'âge absolu est de 4920 ± 140 ans BP (éch. PG 79, GIF 2209) (Giresse, Kouyoumontzakis 1971).

Au Gabon des carottages et des sondages effectués à Port-Gentil ont permis à Nicklés (1952) de définir une faune de Mollusques quaternaires en deux passées entre —15 et —20 m et —27 et —32 m qui sont des sédiments de niveaux transgressifs certainement nouakchottien.

Sur le plateau continental, nous possédons une datation pour une carotte de 80 cm prélevée à —110 m de fond, la base de celle-ci montre un âge supérieur ou égal à 35 000 ans (PN 1198 g, GIF 3233), mais les espèces pélagiques contenues

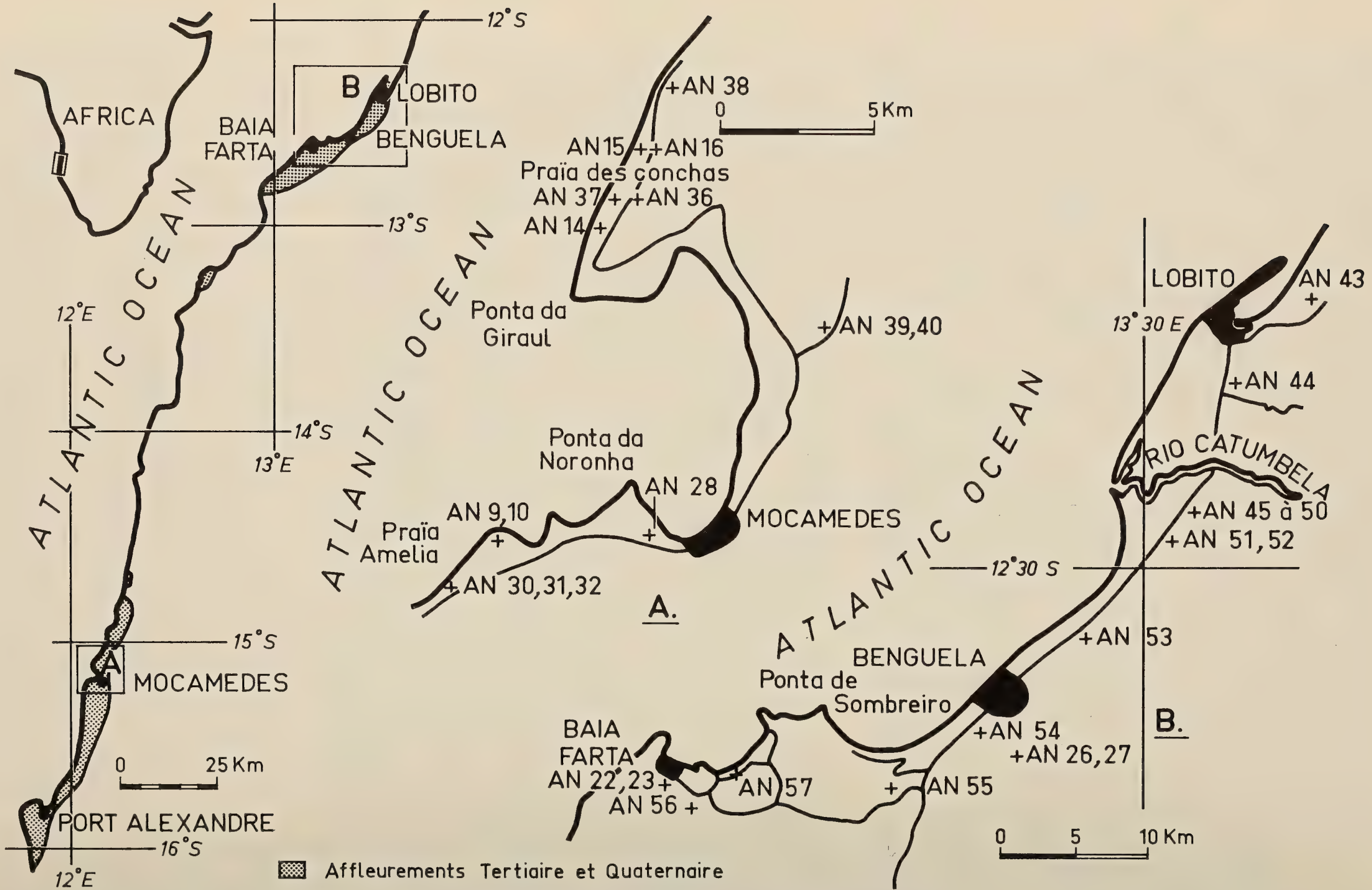

Fig. 7. Les secteurs et les dépôts considerés dans le texte.

dans la microfaune de ce sédiment sont en cours de détermination et ne permettent pas de donner la profondeur de dépôt de cette association thanatocoenotique. Il peut donc s'agir d'un dépôt formé durant la période transgressive inchirenne (—25 000 à —40 000) ou la période régressive aguerguerienne (—40 000 à —70 000).

Les seuls dépôts de surface que nous avons trouvés et qui semblent correspondre à un niveau récent Tafolien (—4 000 à —2 000) sont des sables blancs qui résultent d'un épisode éolien, de même la présence de tourbes de mangrove dans le bassin des fleuves côtiers et la largeur de leur plaine estuarienne démontrerait une transgression récente.

Il est donc important de constater que les dépôts quaternaires trouvés en altitude au Sud de l'Angola, voient leur altitude diminuer et celle-ci devient négative au Nord du fleuve Congo. Les derniers niveaux quaternaires cités à terre le sont au Zaïre et au Cabinda (Dartevelle 1950; Rémy 1954). Plus au Nord et jusqu'à l'Afrique Occidentale le 'quaternaire sl' n'affleure plus.

Peut-être des dragages systématiques sur tout le plateau continental entre le Gabon et la Côte d'Ivoire permettrait de trouver l'explication de ces phénomènes et de relier les affleurements sous-marins du Congo avec ceux de la Côte d'Ivoire (Martin 1973) et de la Guinée et de la Sierra Léone (MacMaster *et al.* 1970).

Des observations d'ordre faunistique vont nous permettre ensuite de définir les aires d'extension géographique et chronologique du courant froid de Benguela.

Les auteurs portugais parlent au fond de la Baïa do Chapeu Armado d'un site Ouljien à madréporaires à une altitude de 8 à 20 m.

Cet animal déjà cité par Faber en 1926, est rattaché par Carvalho (1961*b*) à l'espèce *Siderastrea siderea* Ellis et Solander; Chevalier & Hebrard (1967) citent dans l'Inchirien de Mauritanie un *Siderastrea radians* Pallas daté vers 31050 ans BP.

Ces auteurs pensent que *Siderastrea siderea* cité par Carvalho pourrait être rattaché à l'espèce *Siderastrea radians*, cette espèce pouvant vivre en milieu à apport terrigène, exposé à l'air, au soleil et pouvant subir des abaissements de salinité et de *température dans des conditions exceptionelles.* Dans le cas nous intéressant, la faune collectée sur le même site est une faune chaude de milieu infralittoral qui n'existe plus actuellement que dans les eaux guinéennes, ou les eaux sursalées et surchauffées de baies fermées dans les régions actuellement baignées par le courant froid de Benguela.

La faune qui accompagne ces madréporaires est de même composition qualitative que la faune des affleurements GKAN 14, 16, 36, 39, 40 et paraîtrait donc avoir une âge nouakchottien, cependant, en l'absence de datations absolues, nous sommes amenés à faire deux hypothèses.

(*a*) Les gisements à *Siderastrea radians* sont inchiriens.
(*b*) Ils sont nouakchottiens.

Si les *Siderastrea radians* ou *siderea* sont inchiriens la présence du courant de Benguela sur les côtes d'Afrique peut être infirmée jusqu'à moins 25 000 ans BP, par contre si ils sont d'âge nouakchottien, la présence du courant de Benguela ne remonterait qu'à 4 ou 5 000 ans BP.

En outre, au cours des récoltes de faune sur les plages du Congo entre le 4° et le 5° de latitude Sud, nous avons ramassé des *Astrangia* sp. Quel que soit leur lieu de récolte, ces animaux n'ont jamais été observés vivants et la plupart du temps, sont ou brisés ou recouverts d'une épifaune. De même au large du littoral du Congo, au cours de dragages, nous avons récolté, sur un replat à 110–115 m de profondeurs, des polypiers solitaires semblant appartenir à l'espèce *Caryophyllia clavus* Sc. Ces animaux présentent le même degré d'abrasion que les animaux trouvés sur la côte; on ne les a jamais trouvés vivants.

Cette 'plage fossile' de —110–115 m nous a fourni une faune de mollusques d'eaux plus chaudes qu'elles ne le sont de nos jours, actuellement on trouve ces animaux sur le bord Nord du Golfe de Guinée, en Côte d'Ivoire.

Au point de vue microfaunistique, on trouve dans cette 'plage' de très nombreuses *Amphistegina lessonii* d'Orb. qui vivent en général dans des eaux chaudes et associées à des faciès coralligènes. Ces foraminifères ont été datés de l'Holocène PN 596 (GIF 2564) 11980 ± 250 BP, PN 611 (Fontes) 12620 ± 240 BP.

Il a donc fallu pour qu'ils vivent là que le courant de Benguela n'ait pas existé à cette époque, soit entre 12860 et 11730 BP, car la zone datée est comprise dans sa zone actuelle d'extension.

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HOLOCENE SUBMERGENCE ON RÉUNION ISLAND (INDIAN OCEAN)

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(With 5 figures and 1 table)

ABSTRACT

A series of dates obtained from samples of coral taken from a core drilled into the fringing reef of Réunion Island shows that during the last 7 300 years sea-level has risen continuously, although at a progressively decreasing rate, until it reached its present position. Between 7 300 and 5 600 years B.P. sea-level rose at the rate of 0,59 cm/year; from 5 600 to 3 500 years B.P. the rate of rise was about 0,29 cm/year. Since 3 500 years B.P. the sea has transgressed at a rate of 0,10 cm/year.

The clear increase in the rate of transgression relative to the rates suggested in other areas could be the result of compensatory eustatic processes which tended to offset the delayed beginning of the Holocene transgression in this part of the Indian Ocean. Astronomic and/or oceanographic factors would account for the obvious differences observed in the eustatic movements better than unusually rapid subsidence of the island.

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INTRODUCTION

The coral reefs of Réunion were long neglected by research workers. The first morphological studies were undertaken in 1970 (Faure & Montaggioni 1970; Montaggioni 1970). The present study concerns the mechanics of the Holocene transgression in the Mascarene Archipelago. It is based on eight radiocarbon dates obtained from core samples from the fringing reef of La Saline.

LOCATION AND CHRONOSTRATIGRAPHIC DATA OF THE CORE

Situated in the western Indian Ocean, at 55.32E, 21.07S, the island of Réunion consists of two shield volcanoes dating from between the end of the Pliocene and the present time (McDougall 1971). The mountainous and very rugged topography of the hinterland (maximum height 3 069 m) is extended into a very narrow submarine platform (maximum width 7 km). In consequence the total surface of the coral reefs (12 km^2) is negligible compared with that of the island (2 500 km^2). (See Fig. 1.)

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Ann. S. Afr. Mus. **71**, 1976: 69–75, 5 figs, 1 table.

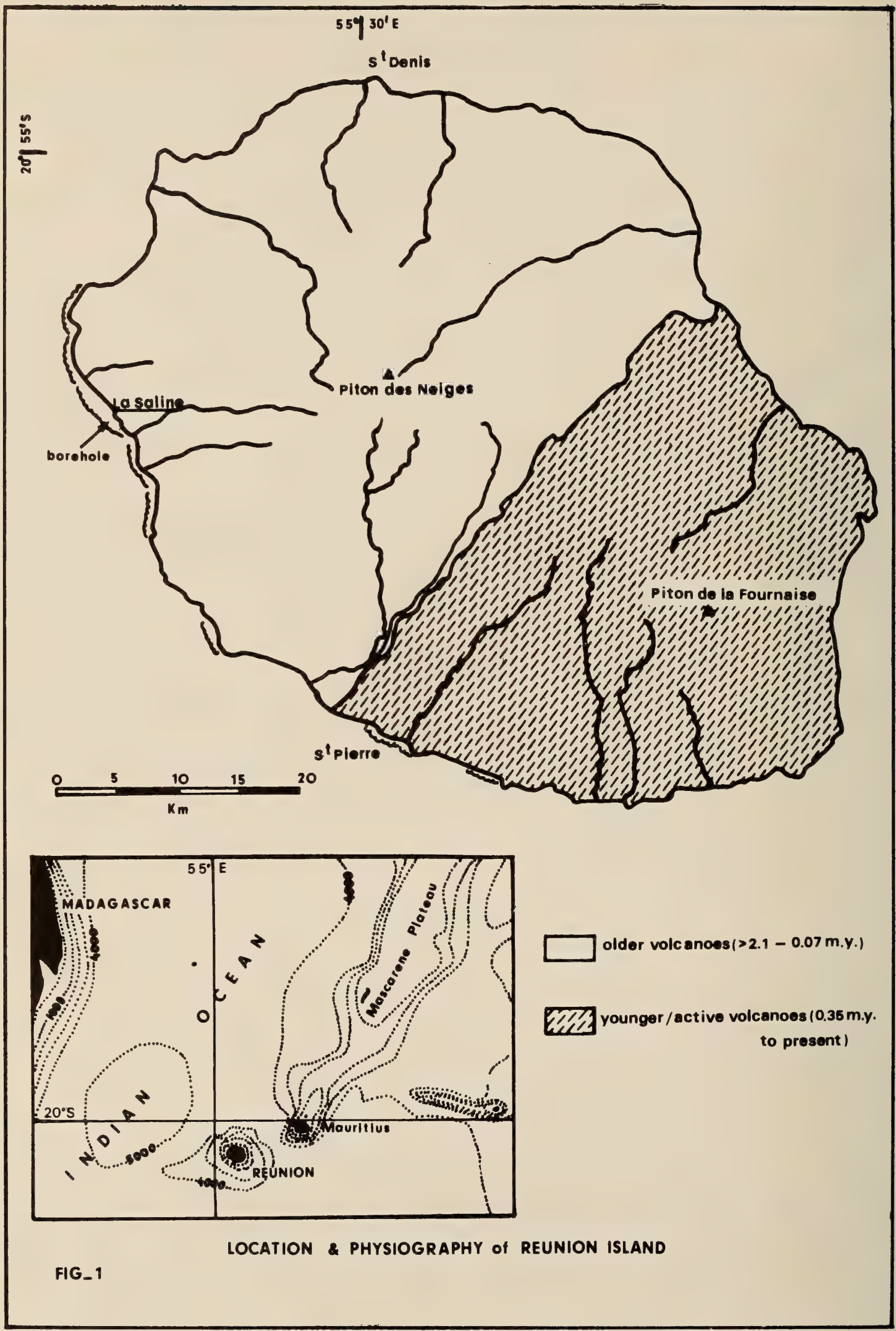

Fig. 1. Location and physiography of Réunion Island.

In 1972 core-drilling was conducted on the fringing reef of La Saline–Trou d'Eau on the landward side of the reef flat (*Acropora pharaonis* flat) at a distance of about 150 m from the seaward side of the reef. The core, which did not reach the volcanic bedrock, was about 18 m long. The sedimentary material which was obtained consisted mostly of coral fragments of which more than 80 per cent comprised the remains of branching *Acropora* forms (Fig. 2).

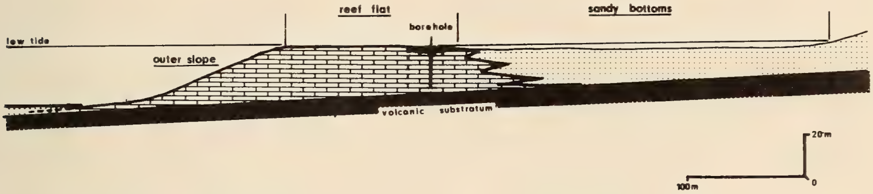

Fig. 2. Schematic cross-section of the fringing reef of La Saline.

The stratigraphic position and radiometric age determinations of the coral samples are given in Table 1. Dates were obtained by Kigoshi, Gakushuin University, Tokyo.

Table 1. Depth and age of coral samples

Field Sample No.	*Laboratory Sample No.*	*Depth in metres of sample relative to present sea-level (low tide)*	*C¹⁴ age B.P.*
FRE 1	Gak 5067	1,2 to 1,3	3 110 ± 90
FRE 3	Gak 5069	4,2 to 4,3	4 950 ± 120
FRE 4	Gak 5070	5,3	4 840 ± 100
FRE 5	Gak 5071	6,8	5 390 ± 120
FRE 6	Gak 5072	9,6	5 860 ± 130
FRE 7	Gak 5073	11,3	6 380 ± 115
FRE 8	Gak 5074	13,8	6 870 ± 150
FRE 9	Gak 5075	18,0	7 280 ± 120

These radiometric dates make it possible to calculate the average rate of reef accretion which was about 0,4 cm/year with maximum and minimum values of 1,02 and 0,11 cm/year respectively. This average value is clearly less than that suggested by Vaughan (1919) for branching forms with a rapid rate of growth like the genus *Acropora* (2,55 cm/year). The average speed of reef accretion is, however, closely comparable to the 0,4–0,8 cm/year suggested by Vaughan (1919) and Hoffmeister & Multer (1964) for massive coral forms. Moreover, it is clear that there has been a general and progressive decrease in the rate of reef accumulation during the last 7 000 years.

The sum of the foregoing evidence suggests the influence of a major ecological factor such as emergence which would inhibit the growth of the coral; in this way the upper members of the living coral colonies would be closely controlled by the level of spring low tides throughout the Holocene marine transgression. As a result, the position of the corals in the reef structure may be considered as an excellent indicator of the level of spring low tide during the Holocene transgression (Easton & Olson 1974).

RATES AND MECHANICS OF SEA-LEVEL RISE

Figure 3 shows the curve of median eustatic sea-level rise during the last 7 300 years.

On Réunion Island the sea-level rose at a rate of 0,59 cm/year between 7 300 and 5 600 years B.P. (Fig. 4). This rate seems very high by comparison, for example, with those obtained for the same time period on New Caledonia (0,29 cm/year: Baltzer 1970) along the west coast of America (0,33 cm/year: Redfield 1967) and in the Netherlands (0,32 cm/year: Jelgersma 1966).

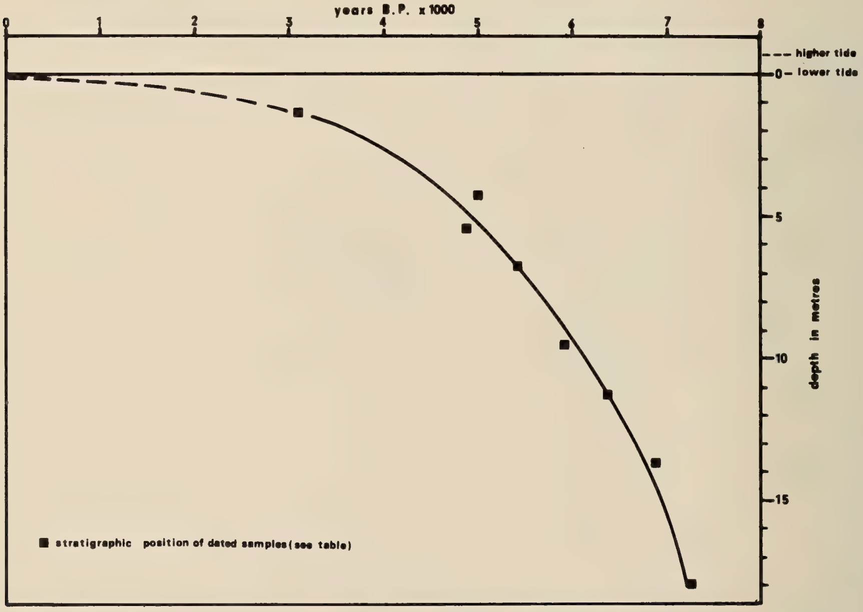

Fig. 3. Holocene submergence of Réunion.

Between 5 600 and 3 500 years B.P. the rate of sea-level rise declined markedly to 0,28 cm/year (Fig. 4). Easton & Olson (1974) obtained a comparable result (0,29 cm/year) on Oahu. On the other hand the world eustatic curve shows a rate of 0,17 cm/year (Shepard 1963) during the same period. Bloom (1969) maintains that this rate of 0,17 cm/year is of purely eustatic origin in Micronesia. If this latter assertion is correct the obviously much greater velocity of transgression on Réunion must have been due to the addition of isostatic effects to account for the increase of approximately 0,10 cm/year in the rate of subsidence of the island. Such a rate of subsidence would, however,

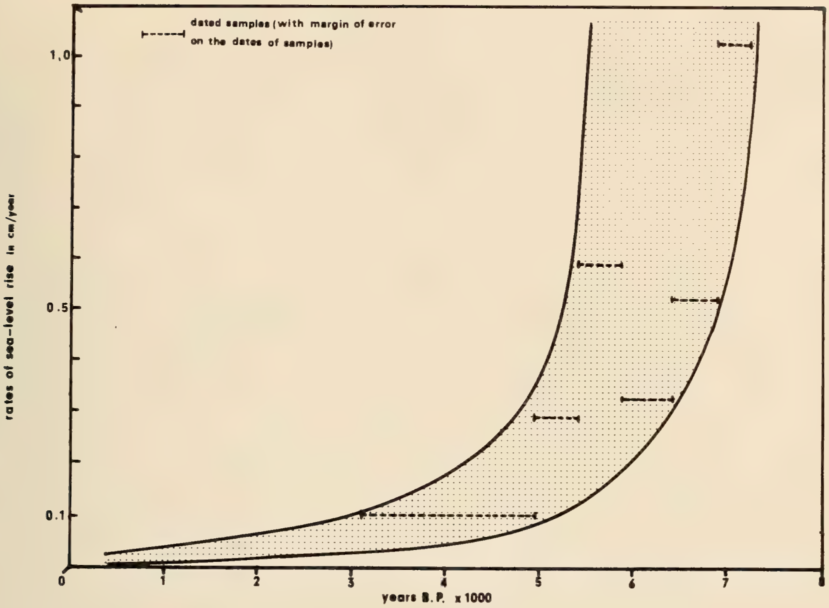

Fig. 4. Rates of rise of sea-level on Réunion.

appear too high if one considers those suggested for other subsiding volcanic areas: Micronesia (0,03 cm/year during the last 10 000 years: Bloom 1969), Mururoa (0,006 to 0,012 cm/year during the last 8 m.y.: Labeyrie *et al.* 1969) and atolls in the Pacific Ocean (average rates of submergence 0,002 to 0,004 cm/year: Hess 1965). The rates generally accepted for the degree of subsidence appear to be negligible by comparison with average speeds of transgression, being only about as great as the errors allowed on the calculation of these velocities of transgression. This being the case, the phenomenon of subsidence could not account for the large real differences in the rates of transgression on Réunion.

Furthermore, prior to 5 500 years B.P. sea-level seems to have been 2 to 6 m lower on Réunion than eustatic level elswhere, according to evidence recently discovered in various parts of the world (Fig. 5). Conversely, the suggested curve seems to provide evidence that sea-levels were slightly higher on Réunion than elsewhere from 5 500 to 3 000 years B.P. This lack of correlation in the height of sea-levels during the period under discussion appears to be part of a general world-wide trend. Schofield (1967) and Morner (1971) postulate respectively that this was due to the effect of astronomic and/or oceanographic factors such as the uneven distribution of ocean waters consequent upon the local addition of large amounts of glacial melt-water, variation in the density of ocean water or else fluctuations in the rate of rotation of the earth. Schofield (1967: 116) wrote that 'the level in the higher latitudes must have been initially higher than those in the equatorial regions'.

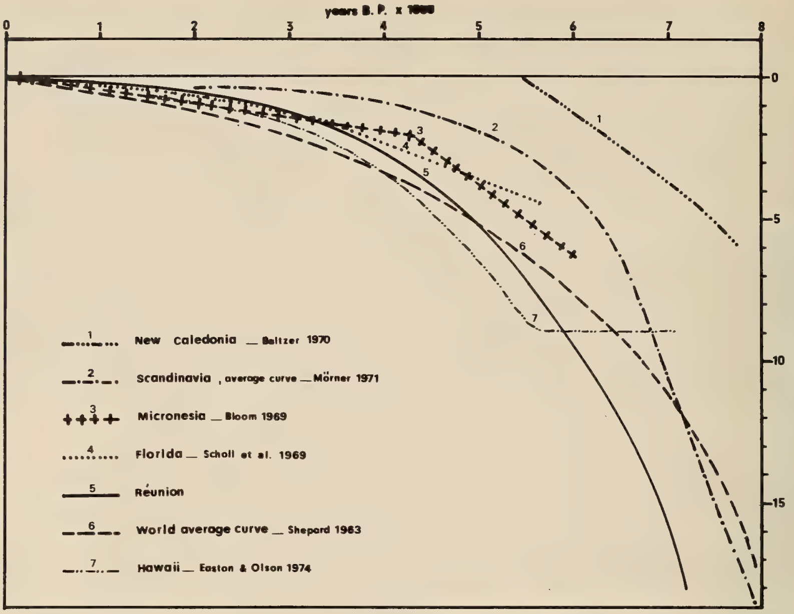

Fig. 5. Comparison between sea-level curves of Réunion and other countries.

One might therefore suppose that around 7 000 years B.P. there was an increase in the rate of sea-level rise to compensate for the delay in the beginning of the first movements of the Holocene transgression in the Mascarenes. After 5 500 years B.P. the rate slowed progressively in sympathy with world-wide reduction in the velocity of marine transgression (Scholl *et al.* 1969) and the partial attainment of eustatic equilibrium in this part of the Indian Ocean. However, the abatement of this compensatory increase took place gradually (on Réunion the velocity of transgression remained higher than the average generally accepted rates) and ceased completely only when the sea reached its present position which it has never surpassed (Montaggioni 1973).

CONCLUSIONS

1. The eustatic curve obtained indicates that sea-level has risen continuously, although at a generally decreasing rate, during the last 7 300 years. This phenomenon seems to have been general throughout the world.
2. In the Mascarenes the Holocene transgression began later than in other geographic regions. This delay could have been due to oceanographic and/or astronomic factors.
3. The relatively high rates of increase in sea-level height could have been due to a process of eustatic compensation which would tend to make good the differences in sea-level. An isostatic origin (subsidence) for such rates must be discounted.
4. The sea reached its present level without ever surpassing it.

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LATE PLEISTOCENE CHANNELS AND FLANDRIAN SEDIMENTS BENEATH NATAL ESTUARIES: A SYNTHESIS

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(With 2 figures)

ABSTRACT

Borehole investigations in Natal estuaries reveal late Pleistocene bed-rock channels buried beneath complex sequences of marine, lagoonal and fluvial sediments deposited during and since the Flandrian transgression. The dimensions of these channels are conditioned primarily by the size and gradient of the contributing watersheds and, for the larger rivers, indicate that sea-level fell to more than −55 m below the present during the Weichselian Stage. Sandy marine sediments accumulated as wedges in the larger estuaries during the Flandrian transgression, but are now found only as barrier deposits along the open coast. Lagoonal sediments accumulated as black to grey organic-rich clays, silts and sands during and after the transgression, but in recent times have been largely masked by continuing fluvial deposition. Owing to fluvial scour and fill, which may range over 20 m vertically during major floods, the radiometric dating of organic debris from these deposits reveals little useful data concerning the progress of the Flandrian transgression. The Mgeni Estuary, north Durban, is discussed to illustrate the kinds of evidence upon which this study is based.

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INTRODUCTION

The following study is based on a detailed analysis of buried bed-rock channels and sedimentation in about two-thirds of the 60 estuaries and lagoons that characterize the 570 km of Natal coast between the Mozambique and Transkei borders (Orme 1974). Sites examined included the Greater St Lucia Lagoon and its nine principal contributing drainages, the Richards Bay Lagoon and its two main contributing streams, and 28 independent rivers that discharge directly into the Indian Ocean without passing through an intermediate lagoonal filtering system other than their own estuaries. Of these, cross-sections for 20 estuaries were constructed by this investigator from raw borehole data supplied by various agencies. The remaining estuaries are generally very small and largely repetitive in detail. From this analysis, a number of observations may be synthesized and conclusions drawn concerning the late Pleistocene

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marine regression and the subsequent Flandrian transgression along the coast of south-east Africa. Figure 1 shows the location of estuaries and contributory drainages in Natal and KwaZulu.

BURIED BED-ROCK CHANNELS

The late Pleistocene bed-rock channels described in this paper were examined as part of a detailed investigation into the nature and magnitude of Holocene sedimentation in the estuaries along the Natal coast. These bed-rock channels are important because the ability of modern estuaries and lagoons to absorb and store sediments is a function of the size of the sedimentary basin below the level of erosion to be anticipated as a result of flood scour and tidal effects. The size of the sedimentary basin is in turn related to the amount of erosion accomplished by Pleistocene rivers attuned to base levels below present sea-level. In general terms, the larger the watershed and steeper the gradient of these rivers, the greater the discharge and velocity of the water, and the greater the erosion and transporting power within their channels. It is thus to be anticipated that the larger rivers of the present landscape may well be flowing seaward over wide and deep bed-rock channels cut during later Pleistocene times. Although the pattern of sea-level changes for south-east Africa during late Pleistocene times has yet to be determined in detail, eolianites and near-shore deposits at depths of up to —100 m off the Natal coast (Anderson 1906; McCarthy 1967) provide some clues to the magnitude of the drawdown to which neighbouring rivers sought to adjust. Data revealed by this present study are consistent with the above assumptions.

The largest river of Natal, the Tugela with a watershed of 28 000 km^2, reveals a bed-rock channel at approximately —50 m below present mean sea-level at a point 6 km above its mouth. The Mfolozi, the second largest river of Natal with a watershed of 10 700 km^2, flows over a bed-rock channel whose floor was not reached by borings at —40 m below mean sea-level at a distance of 34 river km from the sea. Borehole investigations in and around Richards Bay indicate a well-defined buried valley for the late Pleistocene Mhlatuze which descends at least to —55 m below the present surface of the lagoon, and is clogged with Holocene estuarine and barrier-beach sediments. The Mgeni, the fourth largest river of Natal with a 4 400 km^2 watershed, flows seaward over a bed-rock channel at least —52 m below mean sea-level.

Rivers of intermediate size have bed-rock channels of lesser depth—the Tongaat at —30 m, the Mhloti at —31 m, the Mtwalume at —27 m, the Mtamvuna at least —30 m below mean sea-level, and so on. In some instances, such as the Mkomazi Estuary, boreholes have revealed only the edge of what must be a wider and deeper channel. In other instances, such as beneath the Isipingo Flats, no bed-rock channel has been revealed although coarse sands and gravels typical of basal channel deposits suggest the existence of a channel at not much greater depth. Small rivers commonly have small bed-rock channels at com-

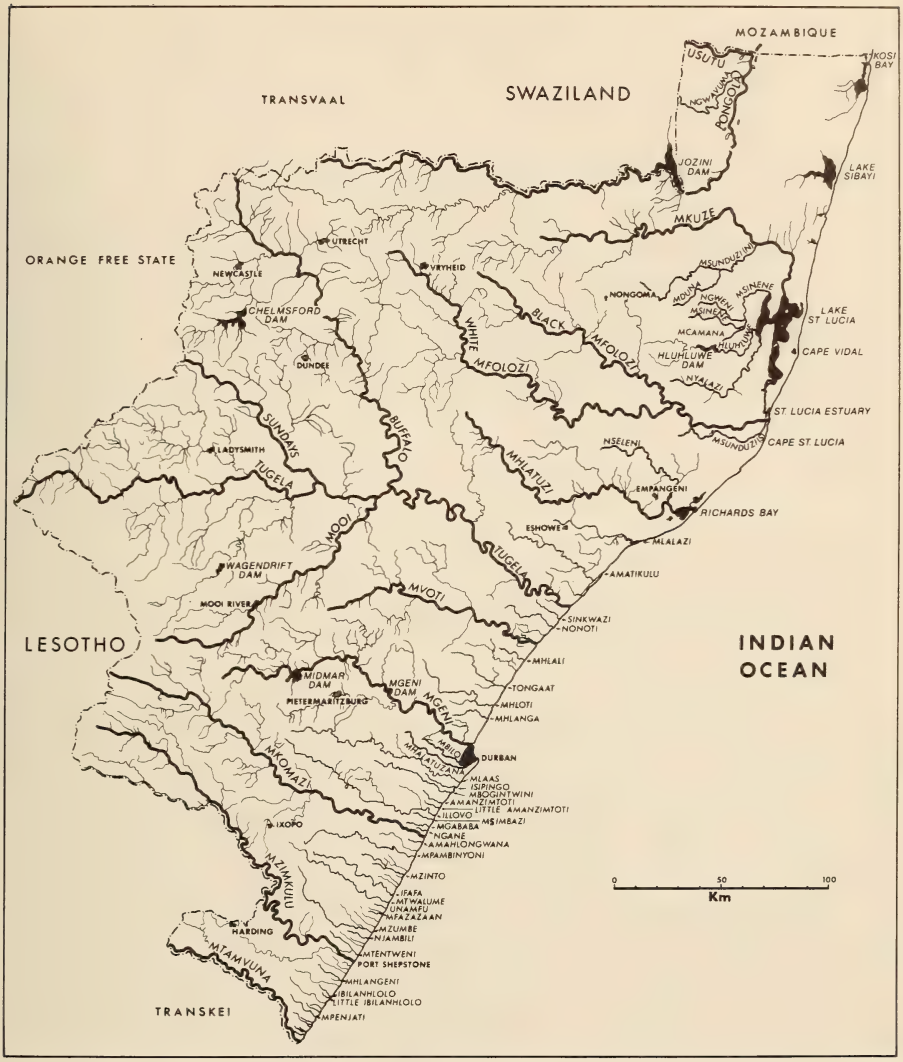

Fig. 1. Location of estuaries and contributory drainages in Natal and KwaZulu.

paratively shallow depth, such as the channel at —12 m beneath the Little Ibilanhlolo.

From these data it is clear that the depth of the buried channels is to be positively correlated with the size of the contributing watershed and that, whereas no definitive conclusions may be reached about the maximum extent of the late Pleistocene marine regression, sea-level must have fallen to at least —55 m below the present, presumably during the Weichselian Stage. The seaward gradient of these buried channels is presumed to continue, though with diminishing slope, across the continental shelf toward a former sea-level as much as —100 m below the present. Although masked by subsequent marine sedimentation, the evidence for such channels might be revealed by geophysical investigations.

The precise dimensions of the buried channels vary considerably, but in many instances a relatively broad bed-rock channel just below mean sea-level, perhaps the Eemian channel from the Last Interglacial Stage, is incised by a deeper, narrower trough, thought to be of Weichselian Age. This relationship is well seen in the Tongaat, Mgeni, Mtwalume, and Mhlangeni Estuaries. The Mtwalume channel is particularly interesting in that two rock terraces are preserved above the deepest trough, stranded perhaps as the river shifted against the south bank during the Weichselian Stage. In general terms, channels excavated in the more resistant sandstones, granites, and shales reinforced with dolerite have steeper slopes than those found in basalts, unreinforced shales, limestones, and saprolites derived from all these rocks.

FLANDRIAN MARINE SEDIMENTS

The Flandrian transgression, which commenced some time before 15 000 B.P. and culminated around 5 000 B.P., flooded the bed-rock channels described above and produced the slack-water estuarine environments in which deposition of marine, lagoonal, and fluvial sediments subsequently occurred. In general terms, fluvial deposits characterize the inner portions of these estuaries, giving way progressively seaward to lagoonal and marine sediments. Such facies changes are particularly well illustrated in the sedimentary records beneath the larger estuaries. Such records are rarely simple, however, primarily because flood scour and fill have frequently disturbed the sequence of deposits. Today, for example, major summer floods may significantly disturb estuarine sediments to as much as 10 m below and 10 m above the winter channel bed, and there is abundant evidence to indicate that similar fluvial regimes existed during the Flandrian transgression. It is primarily because of this repeated disturbance of the sedimentary sequence by scour and fill that attempts to define the progress of the Flandrian transgression by reference to radiometrically dated organic debris contained within individual strata have proved unsatisfactory.

Marine deposits are found in Natal estuaries in two principal sedimentary situations: either as materials carried into the estuary by wave and tidal action during the Flandrian transgression, or as sands washed and blown over the coastal barriers and spits during and since the close of the transgression.

The first category of deposits is not found in the shallower estuaries that are subject to total scour at the present time, nor are such deposits found toward the inner regions of major estuaries where fluvial scour and fill predominated during the transgression and persist today. Toward the sea in the larger estuaries and lagoons, however, such deposits may form substantial wedges in the sequence. In the Mgeni Estuary near its mouth, for example, a

10 m thick wedge of fine sand with abundant shell fragments at a depth of —5 to —15 m suggests a marine incursion toward the close of the Flandrian transgression before the coastal barrier had accumulated (Fig. 2). The light grey, medium sand with shell debris beneath the Isipingo Flats at —2 to —8 m suggests the last marine incursion into the estuary prior to the development of the present swamp facies. The marine materials are essentially sands ranging from fine to very coarse in texture.

The second category of marine deposits, namely sands forming the coastal barriers and spits, and washed or carried over into the estuaries by waves and wind action, are found across the mouths of all estuaries. Sections through the Little Ibilanhlolo and Mtamvuna Estuaries along the Natal South Coast reveal the position and character of the modern barrier spits particularly well. In the former, the sand-spit forms a wedge which thickens to 4 m across the estuary, lying upon earlier flood deposits. In the latter locality, fluvial deposits are overlain by up to 13 m of medium to coarse sand that extends as a spit for over 300 m across the estuary. The Mkomazi and Tongaat Estuaries also illustrate this characteristic, though the Tongaat sand-spit merges without marked discontinuity into estuarine muds and sands. The nature and magnitude of recent barrier growth across Natal estuaries have been examined in detail elsewhere (Orme 1973, 1974) and will not be discussed further in the present context.

FLANDRIAN LAGOONAL SEDIMENTS

As Natal's estuaries began to assume their present shape during the Flandrian transgression, lagoonal silts and fine sands accumulated on the margins of fluvial deposition, while finer silts and clays accumulated in deeper water and also in backswamps to the side of the main drainage channels. These deposits included much organic material, derived in part from trees and other vegetal fragments washed into the estuary or lagoon by inflowing rivers, and in part from the vegetation growing within the estuary.

In the shallower estuaries, in which earlier Flandrian sediments have been mostly removed from the bed-rock channel by subsequent flood scour, lagoonal deposits are found mainly toward the top of the refill sequence and are of comparatively recent origin. In the deeper estuaries, however, lagoonal deposits may occur at intervals throughout the sequence beneath the depth of present flood scour. Such strata represent lagoonal facies that accumulated during the Flandrian transgression, both during temporary stillstands during the rise of sea level and as backswamp deposits to the side of the main estuary.

The thick lagoonal sequences found in the Mfolozi and Mgeni Estuaries are excellent illustrations of this phenomenon. Black to grey organic-rich clays and silts occur in several lenses beneath the Mfolozi valley and the 10 m thick swamp facies toward the top of the sequence must represent the last stages in the infilling of the Greater St. Lucia Lagoon, subsequently overwhelmed by more recent flood deposits. A similar sequence occurs beneath the Mgeni, and again, a black organic-rich clay merging into a black silt must indicate lagoonal conditions just before the estuary became clogged with sediments and the river began to braid with difficulty through its recent fluvial deposits. This lagoonal deposit lies over a marine sand in which a stream channel was carved and filled with brown sand. In some of the broader embayments where little recent fluvial scour has taken place, as at Isipingo, Amanzimtoti, and Msimbazi, lagoonal muds of recent origin are relatively extensive, ranging from black clays to fine dirty silts and clays.

Since the close of the Flandrian transgression, most Natal estuaries have further diminished in size as a result of fluvial deposition. This will not be discussed here. Lagoonal sedimentation is now confined to comparatively small areas while marine deposits are restricted to barriers at the mouths of the estuaries.

THE MGENI ESTUARY: A CASE STUDY

The Mgeni River drains the fourth largest watershed in Natal (4 400 km^2) and reaches the Indian Ocean through the northern suburbs of Durban. Because of its watershed's importance to the water supply of Durban and Pietermaritzburg, and because its lower reaches were formerly a major obstacle to road and rail communications north of Durban, the Mgeni is the most thoroughly studied of Natal rivers. Between 1958 and 1961, its mean annual flow was gauged at 12,5 m^3/sec and its suspended sediment load was estimated to be 0,07 $\times$ 10^6 tons annually, or less than 0,7 per cent of the load carried by the Tugela. Its mean discharge varies seasonally from 18,4 m^3/sec during the summer rainy season to only 6,5 m^3/sec during the winter.

The Mgeni rises in open hill country at an altitude of 1 829 m some 32 km east of the Drakensberg, in an area that experiences more than 1 000 mm of precipitation annually. Unlike many Natal rivers, the Mgeni's upper course is relatively open whereas the last 40 km above the floodplain around Durban cross deeply dissected terrain in The Valley of A Thousand Hills where deeply decomposed Archaean granites contribute abundant debris to the river. The last 16 km toward the ocean are typified by a wide sandy river-bed composed of abundant granitic debris, with a mean gradient of 2,6 m/km. Because of the seasonal variability of its flow, the Mgeni may also be temporarily blocked at the ocean by a sandy barrier, its waters spreading both north and south into a 3 km-long lagoon parallel with the shore. Historical records from the period of the early British colony in the mid-nineteenth century suggest that the Mgeni, on some occasions at least, was diverted by this barrier southward into Natal Bay (Durban Harbour). The Blue Lagoon, now little more than a small swamp immediately south of the Mgeni Estuary, is a remnant of this former diversion. Borehole data are forthcoming from several localities along the lower reaches of the Mgeni and these will now be discussed in sequence downstream toward the ocean.

Boreholes for the bridge on the new Durban By-Pass, at the confluence of the Mgeni and Palmiet Rivers 7 km above the ocean, reveal a bed-rock channel excavated in Dwyka tillite and Ecca shale to a depth of —25 m below present sea-level. This channel is filled in succession with up to 2 m of basal gravels, up to 15 m of sand with some clay and silt lenses, and an uppermost complex of sands, silts and clays. These deposits are all fluvial in origin and the sequence displays numerous scour and fill episodes. The present river-bed lies only 1 m above mean sea-level and below this point occupies a broad alluvial plain 2 km wide.

In the vicinity of the Connaught Bridge, 2,5 km above the ocean, the flood-plain narrows to 300 m between steep bluffs in a locality that early offered an important bridging point across the Mgeni. The original Connaught Bridge was built at the beginning of this century, and the excavations for this bridge revealed an essentially three-tier sequence of deposits: a basal stratum of 'white sea sand', an intermediate stratum of 'silty clay' with thin layers of sand, and an upper stratum of 'coarse sand'. Boreholes for a new Connaught Bridge obtained in 1958 confirm this general sequence and reveal the basal sand to a depth of —28 m below mean sea-level without reaching bed-rock. This sand contains abundant shells and is in places mixed with small amounts of clay, seemingly confirming a marine incursion into an estuarine environment. The intermediate deposit is more clayey than silty clay and is up to 13 m thick, reaching a base of —24 m below mean sea-level. This stratum is a reasonably typical estuarine deposit. The upper sand is both coarse and rich in gravels, presumably a typical Mgeni flood deposit filling the contemporary scour trough of the river which extends down to 11 m below the present river-bed.

Borings for the new Athlone Bridge over the Mgeni approximately 1 000 m inland from the ocean were conducted in 1964 for the Durban City Engineer, and these have been interpreted by this investigator (Fig. 2). The sequence of events revealed is exceedingly complex, reflecting appreciable lateral and

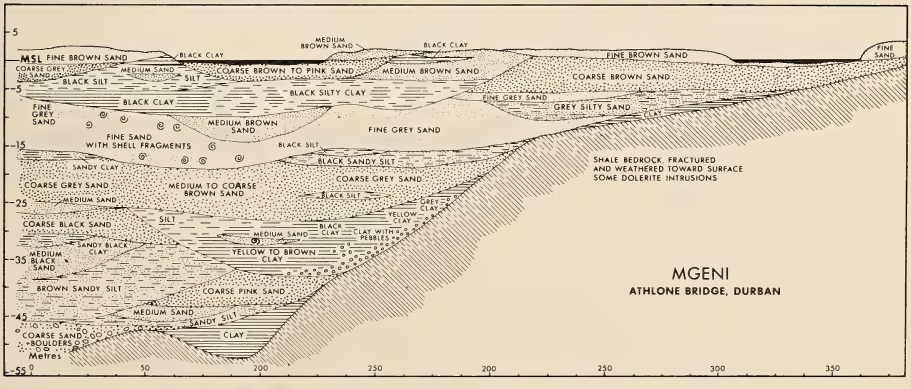

Fig. 2. Cross-section through the Mgeni Estuary along the line of the new Athlone Bridge, north Durban.

vertical variations in the sedimentary record. The bed-rock channel is cut into black Ecca shales which become well fractured and weathered toward their surface, suggesting that the basal clays found locally across the profile may be *in situ* weathering deposits. This bed-rock channel at first slopes gently from the north bank and then plunges more steeply to at least —52 m below mean sea-level. Though the coarse sand and boulders in the southernmost profile were not bottomed during boring operations, they are thought to lie near the floor of this channel. Among the overlying deposits, the dark-coloured, brown to black sands are interpreted as fluvial deposits accumulating in an organic-rich estuarine environment, while the yellow to brown clays are interpreted as lagoonal and backswamp materials. At depths of between —5 and —15 m, a pronounced fine sand occurs with abundant shell fragments, suggesting a marine incursion into the estuary towards the close of the Flandrian transgression, at a time when the coastal barrier was not in position. This fine sand is overlain by lagoonal black clays and silts, and by fluvial brown and pink sands. The base of the coarse brown to pink sand beneath the more southerly arm of the Mgeni is thought to represent the lower limit of normal scour at the present time, though the top of the fine grey sand with shells may have been scoured out by an extreme flood event related to present base level. Pink sands are fairly typical of the Mgeni, having been derived from Archaean granites in The Valley of A Thousand Hills.

Exploratory borings for the Ellis Brown Viaduct across the Mgeni Estuary 200 m inland from the ocean reveal complexity similar to that farther upstream: an irregular bed-rock channel cut into Ecca shale and Karoo dolerite intrusions; lenses of marine sand with shell fragments up to 10 m thick, frequent channel fills of typical Mgeni brown to pink sands and grits, interspersed with clay and silt lagoonal deposits. As is to be anticipated so close to the ocean, incursions of marine sand are more frequent and the deposits much thicker than farther upstream, while fluvial sands are proportionately thinner and finer in texture. The present surface deposits in the estuary—fluvial sands, swamp clays and silts, and washover marine sands—provide a useful reference key to the materials at greater depth.

A sample of wood, *Spirostachys africanus*, from a depth of —29 m in the Mgeni channel has yielded a C^{14} date of 8 420 ± 140 years B.P. (Maud 1968). Assuming that this terrigenous material was then buried by the Flandrian transgression, it lies somewhat deeper than most estimates of sea-level for the time. Whereas extreme views place sea-level around 8 500 B.P. as high as —15 m and as low as —35 m, most investigators favour a —20 to —25 m depth. However, the scour-and-fill character of the Mgeni sequence suggests that the material may have been emplaced at its comparatively low level during the alluviation of a flood channel scoured several metres below the sea-level of the time. Less easily explained is the date of 24 950 ± 950 years B.P. obtained for a peat sample from a black clay stratum in the Harbour Beds at a depth of —22 m below mean sea-level beneath central Durban. These two examples illustrate the difficulties in defining the Flandrian transgression in terms of radiometrically dated debris from estuarine environments.

ACKNOWLEDGEMENTS

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SECTION 2

GEOLOGY B. TERRESTRIAL

CORRELATED ENVIRONMENTAL PARAMETERS AND THEIR BEARING ON PALAEOENVIRONMENTAL RECONSTRUCTION IN INCOMPLETE STRATIGRAPHIC SECTIONS

By

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(With 1 figure)

ABSTRACT

In circumstances under which the probability of sedimentation at a particular locus is correlated with the state of an environmental parameter, systematic loss of information concerning that parameter will occur during subsequent palaeoenvironmental reconstruction based on the preserved sequence. All other parameters whose states vary sympathetically will be similarly affected, whether or not they themselves directly influence sedimentation. Stratigraphic sections with poor time control may not contain clear evidence of hiatus. However, if two or more environmental parameteres are correlated, but with lag, their imprint on the stratigraphic record will be marked by discontinuities.

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INTRODUCTION

Palaeoenvironmental reconstruction, when based on aspects of a sedimentary sequence representing the time interval in question, will be potentially most successful under circumstances where sedimentation at the study locus was more or less continuous, that is, where breaks in the record were short compared to the time intervals over which it is desired that definition of serial changes is to be achieved. Such circumstances are rare in nature, especially in non-marine and intermediate environments, and reconstruction of past conditions must often be based on stratigraphic sections which are incomplete. The time intervals represented by the breaks may not be known, and will not be if palaeontological evidence is lacking, or absolute ages are absent or too few. This is particularly true for short breaks, which will not normally be recognized, especially if evidence of intraformational erosion is lacking.

A lack of preserved sedimentary responses in a section under study may be due partly to their low preservation potential under a specific depositional regime, or to circumstances which precluded any form of sedimentation at a site during a particular time interval.

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The palaeoenvironmentalist dependent on a preserved vertical succession is obviously familiar with the above factors which may reduce the data-yielding potential of his section. As stated above, if the gaps are small compared to the time-scale of the phenomena to be resolved, then no problems exist. But if they are not, as will often be the case in Quaternary investigations, then serious limitations are impressed on the study.

FLUCTUATING ENVIRONMENTAL PARAMETERS AND PRESERVATION POTENTIAL

There is in addition another circumstance, which the author wishes to explore, which imposes further limitations on reconstruction of the palaeoenvironment where incomplete vertical sections are under study. This relates to situations in which the probability of a gap in the record occurring is closely correlated with a particular state of an environmental parameter.

Gaps in a stratigraphic section represent intervals during which a condition of either non-deposition or erosion existed. Such conditions may be influenced by a number of environmental parameters operating singly or jointly. These include, amongst others, temperature, especially as it affects weathering and erosion, precipitation (amount and distribution of), vegetation, eustacy, and tectonism (local or regional). Palaeoenvironmental reconstruction is concerned with these and related elements of the past, and successful identification of previous conditions will depend firstly on the extent to which their fluctuations are impressed on the physical and biological record and secondly, and more obviously, on the degree to which this record is preserved.

Clearly there are circumstances in which the probability of preservation of evidence of a specific environmental state is very low or zero. Thus temporary lowering of base level may cause a halt of sedimentation at some locus near enough to be influenced by the event. Resumption of aggradation would normally follow a recovery of base level, so that the resulting stratigraphic section, containing a diastem or paraconformity, would reveal no information with regard to the nature of the event.

The situation is aggravated if cyclic repetition of the event occurs, since in this circumstance the systematic loss of information will vitiate any attempt to interpret serial aspects of environmental parameters.

CORRELATED ENVIRONMENTAL PARAMETERS

An important corollary is that if the states of two or more environmental parameters are highly correlated in time, then if any one of them strongly influences the probability of stratigraphic preservation, the others will be similarly affected, with the result that systematic loss of data concerning all correlated parameter states will occur. It is necessary therefore, in any particular study, firstly to consider which of the many environmental parameters subject to fluctuation is likely to influence the probability of stratigraphic preservation under the appropriate depositional setting, and secondly the degree of correlation between such parameters and others which do not directly influence the preservation potential. Thus, following the example cited above, in which a change of base level led to a loss of stratigraphic record, a number of other environmental parameters such as temperature and precipitation, whose fluctuations may reasonably be expected to correlate through time with base level, would similarly be poorly registered in the preserved section.

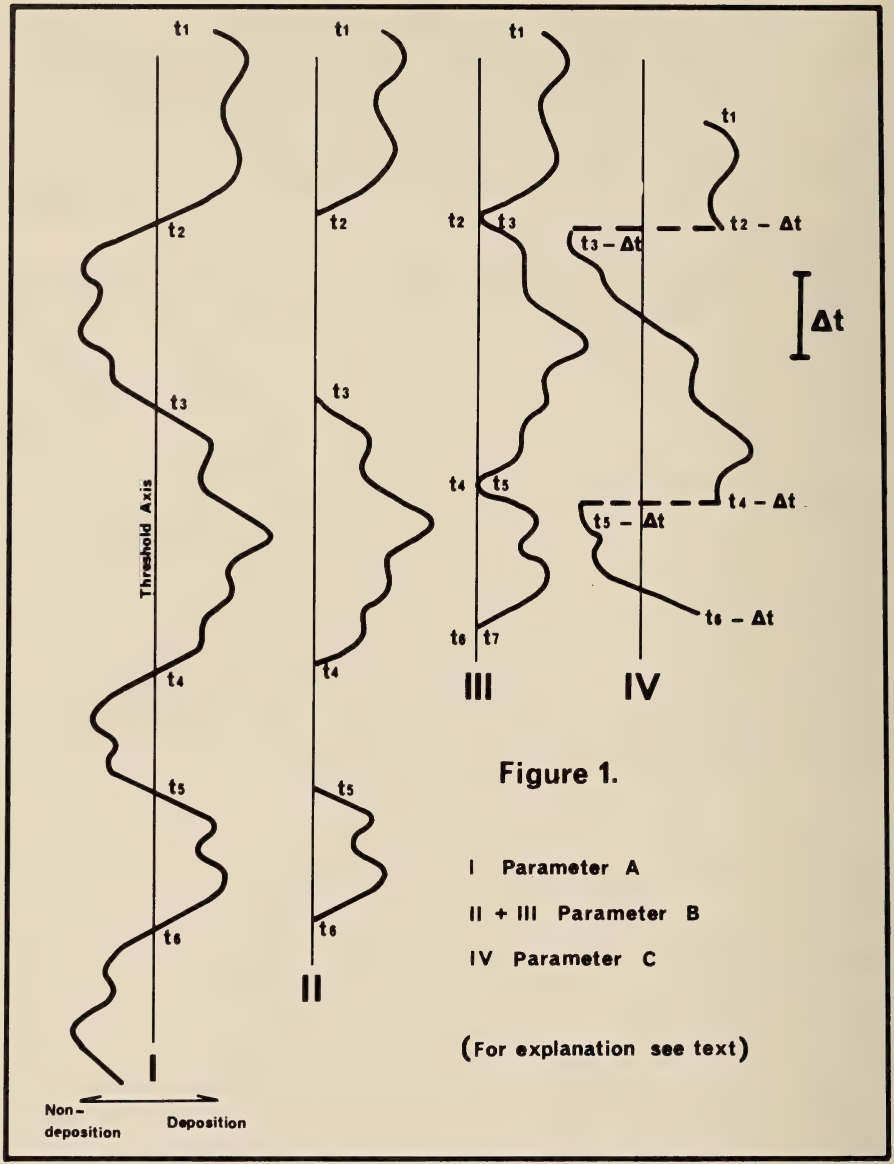
The limitations that these considerations impose on the interpretation of ancient environments will apply especially to situations in which only poor palaeontological control is available. Regional studies, especially with good stratigraphic control, are more likely to provide continuous records in the form of composite sections, where gaps in one record may be filled by observations from another.

In situations where considerable systematic loss of information with regard to certain parameter states has occurred, due to factors such as those outlined above, reconstruction of the palaeoenvironment at times specified by radiometric, palaeomagnetic, or palaeontological criteria are, of course, of undiminished value, so that should the investigator suspect loss of record along the lines suggested, emphasis should be given to those datable palaeoenvironmental conditions that are impressed on the preserved record. However, any attempt to define serial phenomena should be undertaken with caution, especially if one objective is to match parameter fluctuations through time with those recorded at other sites.

THE EFFECT OF LAG

Figure 1 has been prepared to illustrate some of the points raised, as well as to show the result of introducing lag in the correlation of two parameters, one of which directly influences deposition. It is interesting to note that, where no lag exists, no obvious discontinuity in the stratigraphic record occurs (profile III) whereas hiatuses are very sharply defined in situations involving lag.

It will be noted that profile IV was obtained as follows: an environmental parameter A (e.g. base level, rainfall) directly influenced sedimentation, such that certain intervals (t_2–t_3, t_4–t_5) were non-depositional. Assuming that fluctuations in parameter A could be perfectly interpreted through a study of physical or palaeontological elements of the stratigraphic record, curves II and III could be drawn and these curves would also apply to other parameters whose states fluctuated sympathetically with those of A, without lag. If however the stratigraphic section contained physical or palaeontological evidence of an environmental parameter C which fluctuated sympathetically with parameter A but with lag $\triangle t$, then the profile IV would result, bearing a clear imprint of hiatuses which were absent in III. Both profiles III and IV might be obtained from this same section.



Profile I. A fluctuating environmental parameter A is portrayed through time t_1—t_7. For purposes of illustration it is assumed that this parameter directly influences the probability of stratigraphic preservation, so that a threshold axis has been drawn which separates states associated with depositional and non-depositional episodes.

Profile II and III. These curves illustrate fluctuations in parameter A corresponding to depositional episodes in I which may be recorded in the stratigraphic section. Times corresponding to those in I are indicated. The curves can also be taken to represent fluctuations in any other parameter (B) which is perfectly correlated with A. The two curves are identical except with regard to the non-depositional interval.

Profile IV. If the states of a parameter C are perfectly correlated with those of A, but are out of step by lag Δt, then the profile illustrated by IV results. The state of parameter C at the times indicated have been read from I.

LIMITATIONS

Discussion has assumed that there was perfect positive correlation between the fluctuating states of various parameters, and further that the preserved stratigraphic sections contained elements of one kind or another which could be uniquely matched with a variety of palaeoenvironmental states. It is clear that under natural conditions the former assumption is unlikely to be fully justified, and the present state of the art of palaeoenvironmental reconstruction makes the latter somewhat unrealistic. Nevertheless the author considers that in spite of these shortcomings there are broad implications of the arguments presented above which might be of assistance in interpreting stratigraphic sequences.

QUATERNARY SEDIMENTATION AND DEVELOPMENT OF THE LAGOONAL COMPLEX, LAKE ST LUCIA, ZULULAND

By

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(With 10 figures)

ABSTRACT

Lake St Lucia is a saline lagoon on the Zululand coastal plain. It has a surface area of 380 km^2 and an average depth of less than 1,5 m. A compound barrier and a series of parallel relict beach-dune ridges record a succession of depositional events related to Pleistocene sea-level fluctuations. Aeolian sandstones of the penultimate glaciation were planed by the Eem transgression, during which three distinct beach deposits accumulated a few metres above the present shoreline. This high stand flooded the back-barrier area and coral reefs developed in False Bay, the western arm of the existing lagoon system. Sea-level lowering concomitant with the last glaciation initiated renewed valley incision. It was then that the high dunes of the modern barrier originated. The smaller river mouths were sealed by littoral processes during the post-glacial transgression and the lagoonal complex became established. This has been substantially reduced in depth and extent. Coring reveals a maximum of 33,5 m of late Pleistocene and Holocene sediment reflecting a change from marine to estuarine and lagoonal conditions.

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INTRODUCTION

Lake St Lucia is a large saline lagoon on the Zululand coastal plain (Fig. 1). It is separated from the Indian Ocean by a compound barrier, the basal portions of which consist of calcareous sandstones bearing raised marine-cut terraces. These are surmounted by semi-consolidated sandstones followed by loose sands of the high coastal dunes which attain elevations of 180 m.

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Ann. S. Afr. Mus. **71**, 1976: 93–113, 10 figs.

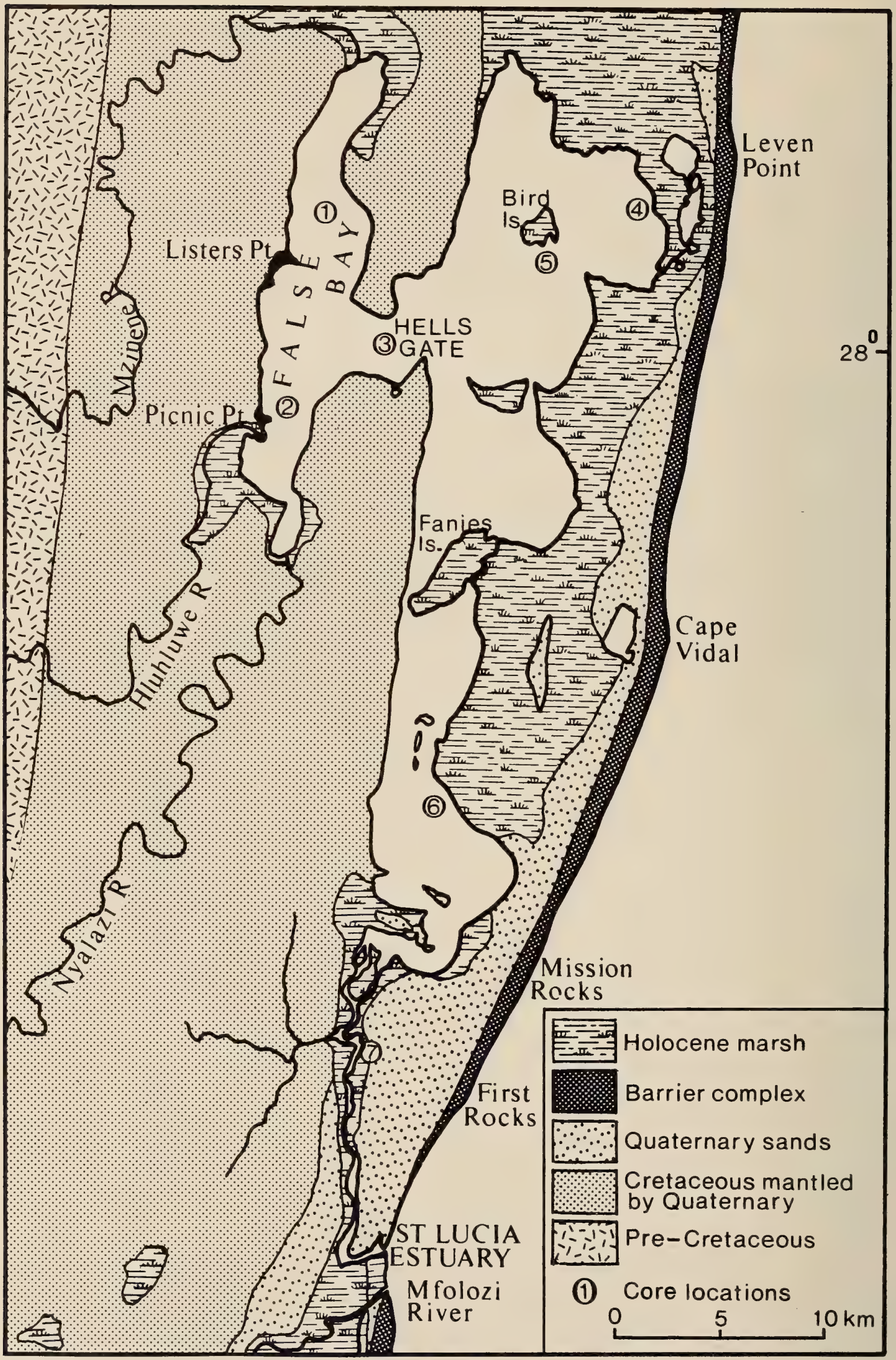

Fig. 1. Generalized distribution of the main geological and geomorphological elements of the Lake St Lucia area. Core sites and other important localities are indicated.

The lagoon comprises two north–south trending bodies of water, False Bay and St Lucia proper, with a connecting strait known as Hell's Gate. The total surface area fluctuates between 420 and 225 km^2 depending upon lake-level. This is in turn determined by the relative intensity of inflow and evaporation, varying from a position some 1,5 m above mean sea-level following floods to below sea-level during times of drought. Fresh water is contributed largely by the Nyalazi, Hluhluwe, Mzinene and Mkuze Rivers, with a combined annual discharge of $45,2 \times 10^6$ m^3. The Narrows, a shallow winding channel, is the only outlet, extending 21 km to St Lucia Estuary. The occasional negative gradient accompanying low lake-levels creates reverse flow of sea water up The Narrows into Lake St Lucia. Prior to its artificial diversion in 1952 the Mfolozi River, with a discharge greater than the total freshwater inflow into the Lake, flowed into the Estuary. It now enters the sea 1,5 km south of its former outlet. Tidal amplitudes of up to 1,6 m in the Estuary are totally absorbed within The Narrows. Rapid wind induced changes in lake level are common, however.

False Bay and the western shores of Lake St Lucia are incised into Cretaceous strata. The gentle seaward dip exposes progressively younger stages from the Neocomian of the upstream Mzinene to the easternmost cliff exposures which probably span the Mesozoic-Cenozoic boundary into the Paleocene. These rocks are sporadically overlain at an elevation of 10 m by Middle to Upper Tertiary coquina ('pecten bed') and sandstone. Above these are the unconsolidated red, brown and grey sand deposits which mantle the coastal plain. The most conspicuous topographic features of the coastal plain are north–south oriented dune ridges, the larger of which are composed of red sand. To the west of Lake St Lucia these commonly have a boulder bed at the base.

In False Bay there are fossiliferous late Pleistocene deposits with a fauna indicative of unrestricted marine conditions. These must have accumulated prior to the development of a continuous seaward barrier. At a later stage the barrier was more substantial and had a profound influence on the nature and rate of sedimentation.

It is the purpose of this paper to outline the salient sedimentary and geomorphic characteristics of the barrier and lagoon and to relate these to the processes involved in their development. It is apparent from the outset that a dominant factor has been eustatic changes in sea-level. Most of the data were obtained from the study of surface exposures and shallow auger samples. Important information concerning the sediments beneath the Lake bed was provided by seven continuous cores obtained during the latter half of 1973 through the efforts of Mr T. Blok in charge of St Lucia Reclamation. The cores extend from the sediment-water interface to Cretaceous bedrock at a maximum depth of over 30 m. Foraminifera, ostracods, diatoms and a variety of macrofossils were extracted and set aside for specialist examination.

THE COMPOUND BARRIER

Several distinct stratigraphic units are exposed along the seaward side of the coastal barrier, but the sandstones do not outcrop along the landward margin where they are mantled by unconsolidated deposits. Certain units are correlative with outctops in the Durban area described by a number of authors including Krige (1932), King & Maud (1964), McCarthy (1967) and Maud (1968).

UNIT 1

The oldest deposits of the barrier consist of fine to medium-grained sandstone which is best exposed at First Rocks and Bats Cave 2 km to the north of Mission Rocks (Fig. 1). This is probably equivalent to the 'Bluff Beds' of Krige (1932) or the 'first aeolianite' of Maud (1968). It extends from an unknown depth below sea-level to a maximum observed elevation of 8 m. The higher parts have been subjected to considerable karst weathering.

Large-scale cross-bedding is a characteristic feature (Fig. 2). Dips range from 8 to 36 degrees and are variable in azimuth, although a strong westerly component is evident in most outcrops. Foreset laminae commonly display evidence of minor slumping prior to lithification. In thin section the rock is seen to consist predominantly of well-sorted sub-angular to rounded quartz grains with diagenetically altered shell fragments and a sparite cement.

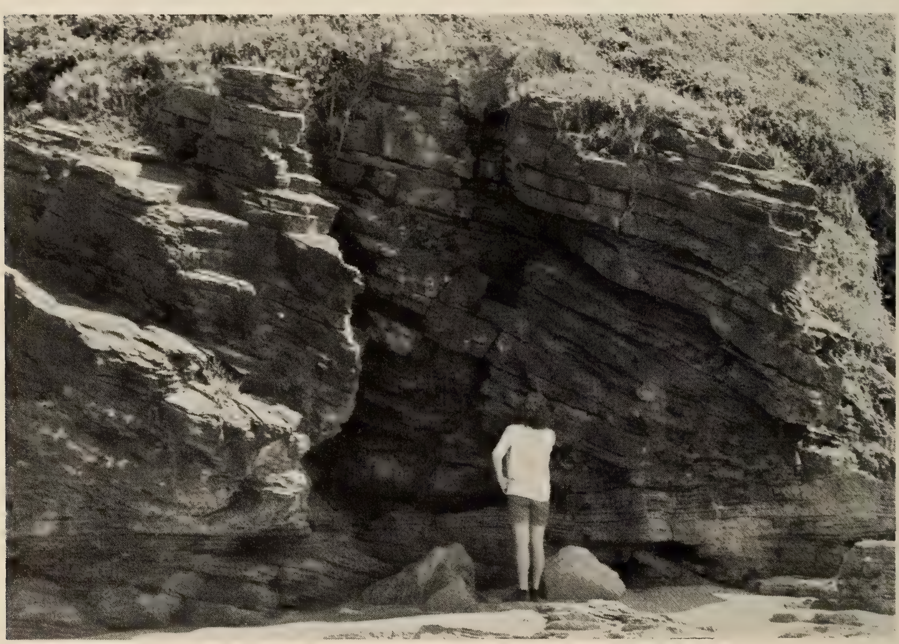

Fig. 2. Aeolian sandstones of unit 1 displaying large-scale cross-bedding at First Rocks.

These attributes together support the interpretation by Belderson (1961) and McCarthy (1967) of an aeolian origin for the equivalent formation in Natal. Sand was presumably piled up as coastal dunes during a stage of eustatically lowered sea-level. Ample sand would have been available from a belt of emergent continental shelf several km wide. Present-day prevailing wind directions are from the north-east and south-west, blowing roughly parallel to the shoreline. During glaciations however, temperature contrasts between land and sea would have been increased, thus leading to a higher frequency of strong onshore winds. This probably accounts for the high proportion of landward inclined foresets in unit 1.

At certain localities, such as Bats Cave, these aeolian sandstones are truncated by a flat, horizontal erosion surface at between 4 and 5 m above sea-level. Elsewhere the surface is less regular, ranging from a height of 8 m to below present sea-level.

UNIT 2

The depressions in this undulating surface eroded into unit 1 are overlain between present spring low tide level and an elevation of up to 5 m by coarser-grained, conglomeratic sandstone. These rocks, here referred to as unit 2, are subdivisible into two distinct facies on the basis of differences in sedimentary structures, and to a lesser extent, in lithology.

The first type consists of low-angle, eastward-inclined planar foresets of medium to coarse-grained sandstone with small discoidal and blade-shaped pebbles composed largely of lydianite. Well-defined parallel lamination dips seaward at between 4 and 10 degrees (Fig. 3). Microscopic examination reveals that these sandstones are less perfectly sorted than the aeolian deposits. They contain in addition to quartz up to 10 per cent feldspar and a variety of mollusc and echinoderm fragments, foraminifera and algae. These deposits strongly resemble the upper foreshore of modern beaches. The preponderance of flattened pebbles of small size (less than 3 cm maximum diameter) is suggestive of the size-shape sorting processes that operate in the swash zone, and the eastward dipping stratification records the successive profiles of a prograding beach. Local discontinuities mark changes in the beach profile.

The second facies occurs at a lower level (generally below 2 m a.s.l.) and is gradational into the upper foreshore beds. It consists of trough cross-bedded sandstone, very similar in lithology to the beach deposits, but differing in the shape of the pebbles. Both flat and equant shapes are represented, and many are almost perfect spheres. Furthermore, the maximum size is slightly larger, some pebbles attaining diameters of 15 cm. Whereas discoidal and blade-shaped pebbles are selectively cast up on a beach, shape sorting results in a larger proportion of equant pebbles being concentrated below low tide level (Bluck 1967). Thus it appears that this trough cross-bedded sandstone facies originated in a nearshore shallow marine environment.

Trough axis azimuths (Fig. 4) reveal that the currents which deposited

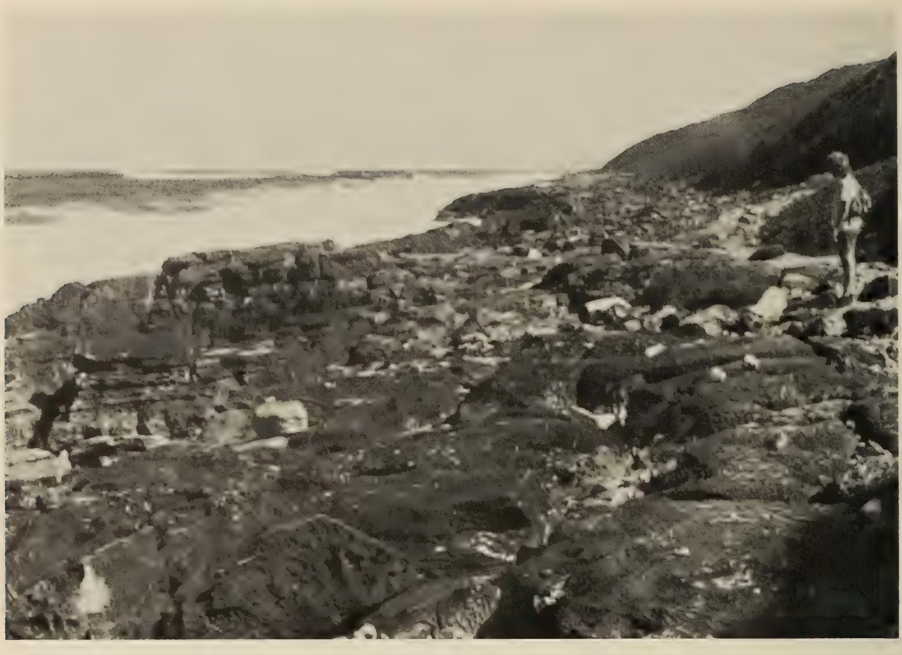

Fig. 3. Upper foreshore deposits of unit 2. The upper surface is planed and overlain by a younger conglomerate and the coastal dunes to the right. Mission Rocks.

these sands flowed in directions which were either sub-parallel or perpendicular to the existing shoreline. Since the late Pleistocene shoreline trend was undoubtedly very similar, these currents were of a semi-permanent longshore variety. Modern-day patterns along certain sections of the Natal and Zululand coasts are very similar. Both northward and southward flowing currents are observed at different times of the year. The offshore directed cross-beds are characteristic components of the nearshore inner rough facies immediately seaward of the swash zone (Clifton *et al.* 1971).

The upper foreshore facies of unit 2 extend to a maximum observed elevation of between 3,5 m and 5 m where they are bevelled by the same seaward-dipping surface that locally truncates the older aeolian deposits of unit 1. Thus the high water level corresponding to the deposition of these beach sands must have been a little more than 5 m above present sea-level and is possibly approximated by a poorly preserved 8 m surface at Bats Cave. Deposition of unit 2 must therefore have coincided with an inter-glacial higher sea-level which succeeded the low stand during which the aeolian sandstones (unit 1) accumulated.

During the ensuing marine retreat, probably related to an interstadial of short duration, these shoreline deposits were lithified, and together with the older sandstones, subjected to karst weathering.

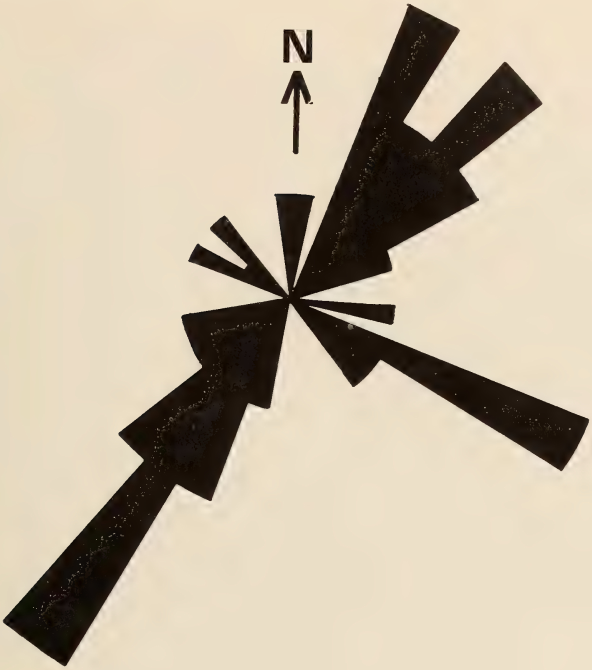

Fig. 4. Distribution of cross-bed azimuths in the lower nearshore facies of unit 2 (34 readings)

UNIT 3

Renewed advance of the sea above its present level planed both aeolian and beach deposits along a seaward-sloping surface at present preserved between 5,3 and 3,4 m. This wave planed surface is mantled by a coarse-grained conglomerate (Fig. 5) which fills in karst depressions and potholes produced by marine abrasion. The thickness of this conglomerate, designated unit 3, is therefore highly variable, ranging from a few cm to 2 m. The inclusions consist of locally eroded clasts of calcareous sandstone together with a variety of extrabasinal pebbles. Of the latter quartzite pebbles are most numerous followed by lydianite and gneiss. Some of the inclusions are of boulder dimensions, the largest encountered measuring 65 cm in diameter. The mean diameter is approximately four times greater than that of the pebbles in unit 2. A discoidal shape predominates. Large numbers of oysters and other abraded mollusc fragments are present locally. Some oysters are preserved in living position in potholes.

Unit 3 is ascribed to transgressive shoreline processes which characteristically deposit coarse shingle. The fact that the coarsest material is preserved in the potholes suggests that these pebbles and boulders were responsible for their abrasion. The sides of some potholes are distinctly undercut. Vigorous

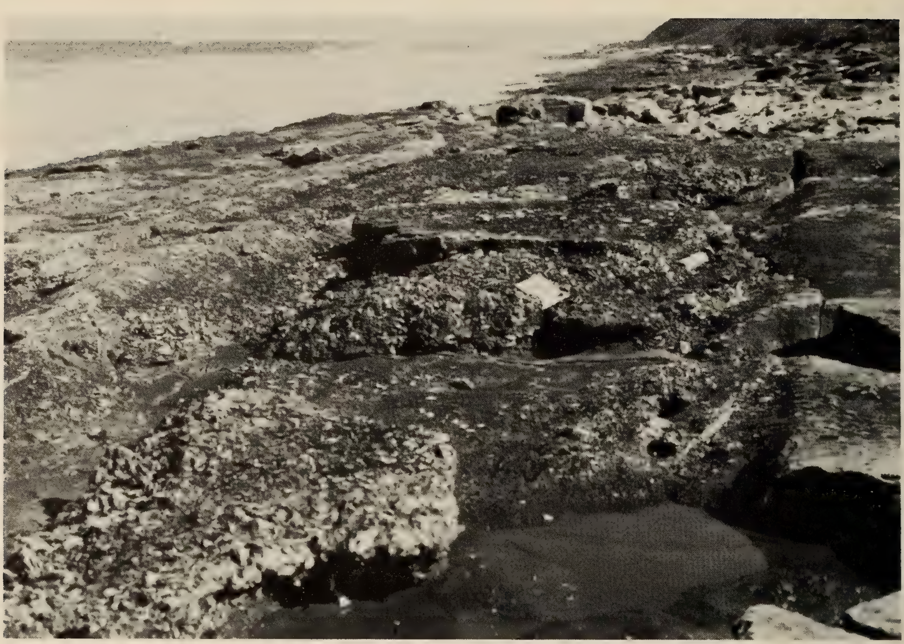

Fig. 5. Elongate depressions and potholes in truncated surface of unit 2 overlain by oyster-bearing conglomerates. South of Mission Rocks.

surf action broke off blocks of sandstone which were later incorporated in the pebbly matrix.

The superabundance of pebbles derived from the Precambrian hinterland suggests that, in addition to the Mfolozi, other large rivers with outlets further north may have been providing this material. There is, however, a northward decrease in the maximum dimension of these inclusions suggesting that the competence of the Mfolozi considerably exceeded other rivers in the area. Larger pebbles are encountered to the north of the Mfolozi than to the south, indicating that beach drift patterns were probably the same as they are today.

Maximum high water mark corresponding to this episode was a little more than 5 m above present sea-level, but could not be determined precisely. It was nevertheless distinctly lower than the previous transgression which had been accompanied by the deposition of unit 2.

UNIT 4

An aeolian sandstone very similar to unit 1 in terms of its composition, texture and sedimentary structures overlies a 4,4 m pebble veneered (unit 3), eroded surface at Bats Cave. The foresets are inclined westward at angles of 35 degrees. This sandstone was apparently not deposited to any great thickness, extending to an elevation of only 10 m at this locality. Nevertheless, the karst and decalcified upper portions suggest that some of the overlying sands were derived by the leaching of this unit.

The limited distribution and thickness of this deposit suggests accumulation during a brief marine regression. A narrow belt of exposed sand would thus have been subjected to deflation, the sand accumulating against the older deposits of the barrier.

UNIT 5

Evidence for at least one further rise in sea-level above the present shoreline comes from a second generation of potholes incised through unit 3 and commonly extending into unit 2 (Fig. 6). These potholes differ from the older variety associated with unit 3 in the preservation of outflow channels produced by seaward runoff. Oysters occur most abundantly in these potholes within 1,5 m of modern spring high water mark. Many adhere to the sides or to one another in living position and there are few reworked fragments. Potholes related to this episode at elevations of up to 4,5 m contain reworked oysters and discoidal pebbles.

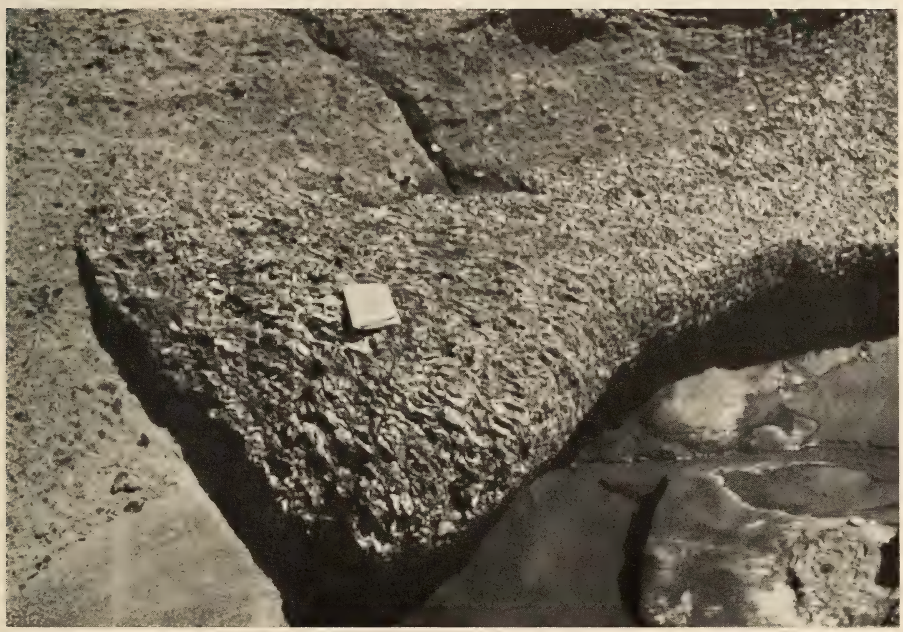

Fig. 6. The three raised beach deposit of the barrier. Unit 5 beneath the scale occupies a cavity in unit 3 which overlies the eroded surface of unit 2. Mission Rocks.

COASTAL DUNES

Practically continuous high coastal dunes extend from Mtunzini northward into Mozambique. They consist of light coloured, almost pure quartz sand with local concentrations of heavy minerals such as ilemnite, rutile, zircon and magnetite. Grain size analysis reveals a normal distribution with a median diameter in the medium sand range.

In places the coastal dunes overlap landward on to an older ridge of red sand. Dune peaks attain an elevation of 188 m to the south of St Lucia Estuary. Between the Estuary and First Rocks to the north they are low and insignificant. Beyond First Rocks two lines of high dunes are separated by a narrow depression.

Deep augering revealed an increasing percentage of heavy minerals, but the absence of a core of older consolidated deposits. The sands have been weakly calcified in places. There is no evidence of the lignite-bearing Port Durnford Formation except to the south of St Lucia Estuary. Excavation of the seaward dune flanks reveals multidirectional cross-bedding. Occasional cross-bedding on a large scale, in sets 10 m thick, is reflected in places by patterns in the vegetation growing on the flanks (A. J. Tankard, pers. comm.). This, together with the topography of the dune crests, suggests that winds from the north-east and south-west have been equally effective.

An origin related to a lowered sea-level is indicated by the present narrow beach, and the dominance of destructive processes which are effectively reducing the average elevation of the dunes. North-easterly winds in particular have produced parabolic blowouts which cause local destruction of vegetation and thus accelerate deflation. Certain dune crests are actually growing in elevation (C. J. Ward, pers. comm.) but this appears to be exceptional.

As with older aeolian deposits sand would have been carried landward across the exposed sandflat. The pre-existing ridge of older cemented sands coincident with the modern shoreline would have localized accumulation as an almost continuous dune belt, broken only by river outlets. Stabilization by vegetation would have occurred during the subsequent climatic amelioration. Further limited accretion of wind-blown sand along the seaward margins has been accompanied by local erosion of the dune base elsewhere depending upon differences in shoreline trend and offshore topography.

POSSIBLE RELATIONSHIP OF BARRIER DEVELOPMENT TO PLEISTOCENE SEA-LEVEL FLUCTUATIONS

Changes in the relative level of land and sea, such as are evident in the Lake St Lucia barrier, are attributable to two possible basic mechanisms, tectonic or eustatic. Monoclinal warping (King & King 1959), although demonstrable on a large scale involving seaward tilting of land surfaces, does not account for the wide extent of low terraces at comparable elevations along much of the east coast of southern Africa (Krige 1927; Davies 1970, 1971). A eustatic origin appears to be the more likely.

There are marked differences of opinion as to world-wide sea-level heights during early and middle Pleistocene times, and also with regard to the validity of Holocene levels higher than the present (Curray 1969). Nevertheless, there appears to be general agreement that during the late Pleistocene, between approximately 75 000 and 130 000 years ago, there were times when sea-level stood several metres higher than at present. It is also accepted by a number of investigators that this Eemian (Sangamon) high was not a single event, but consisted of three peaks separated by slightly lower levels (Fairbridge 1960; Mesolella *et al.* 1969; Emiliani 1970, among others).

It is possible that the stratigraphic units 2, 3 and 5 of the St Lucia barrier correspond with these three Eemian peaks. Unit 1, which is widely developed along the Mozambique, Natal and probably much of the south-eastern Cape coast, is therefore interpreted as originating during the preceding Saalian glaciation.

FOSSILIFEROUS LIMESTONES OF FALSE BAY

Highly fossiliferous limestones containing a variety of corals and molluscs, together with local concentrations of brachiopods and cirripeds, are exposed in very small outcrops at Lister's Point and Picnic Point on the western shores of False Bay (Fig. 1). These rocks occur intermittently along the shallowly submerged shelf bordering these outcrops, and are present in at least two places beneath the surface of False Bay near to the opening into Hell's Gate. An additional small pinnacle protrudes above the mud floor at the south-eastern end of Hell's Gate, and at low lake-level is within a few centimetres of the surface.

The faunal characteristics of the limestones are similar at all localities, but there are differences in the relative abundance of various coral types. At Lister's Point several large colonial corals are preserved in growth position together with scattered solitary forms (Fig. 7), all of which await specialist identification. Casts of branching Acroporidae are the common form in the upper part of the Picnic Point exposure. Large bivalves such as *Hyotissa hyotis*, with a maximum observed length of 23 cm have been obtained along with large specimens of the gastropod *Tonna*. Other commonly occurring molluscs include *Circe scripta*, *Decatopecten* sp., *Polinices sebae*, *Rapana rapiformis*, and *Ostrea*. The barnacle *Balanus* is abundant, along with a small brachiopod of the family Kraussinidae which resembles *Megerlina* (T. Mason, pers. comm.). Also present are sponge and echinoderm fragments and possible crab remains. Trace fossils are mainly large (1–4 cm diameter) vertical tubes with horizontal offshoots and probably include both *Ophiomorpha* and *Thalassinoides*.

Petrographic examination reveals that the bulk of the allochems are biogenic, consisting of mollusc fragments, foraminifera and red algae, with a variable proportion of lithoclasts, mainly quartz. According to Folk's (1959) classification this rock is a biosparite, a well-sorted, moderately high energy deposit, with a sparry calcite cement.

During times of very low lake-level the lower parts of the formation are seen to contain concentrations of spherical to discoidal pebbles of rhyolite, basalt, jasper, chert and lydianite along with many oysters, mainly broken. This merges upward into fossiliferous biosparite with a great variety of fossils, followed by a coral rich zone with a matrix of broken shells. There are con-

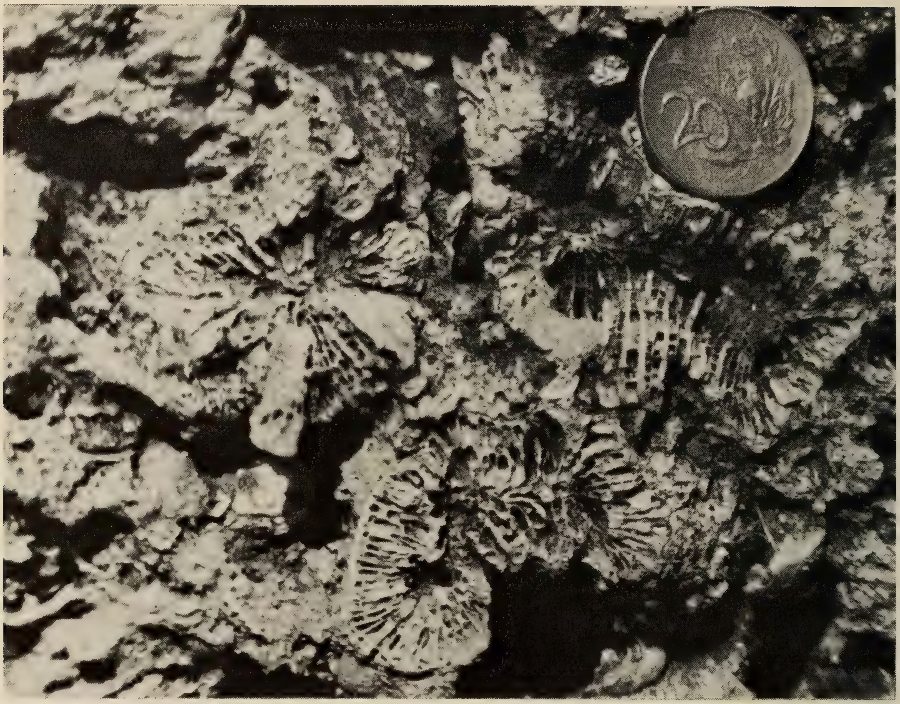

Fig. 7. Coral at Lister's Point on the western shore of False Bay.

spicuous differences between one outcrop and another in the proportion of articulated to disarticulated bivalves and also in the degree of alignment of the fossils. South of Lister's Point up to 50 per cent of the bivalves are articulated and there is a tendency toward upward convexity of individual valves. No preferred disposition is apparent in the predominantly disarticulated valves at Picnic Point.

Along the shores of False Bay the limestones overlie an eastward dipping surface eroded into Cretaceous siltstones. The basal contact is undulatory in a direction parallel to the lake shore. In places there is evidence of intense boring of the Cretaceous surface by marine organisms prior to deposition of the pebble and shell debris. The upper surface extends to a maximum observed elevation of 3,4 m a.s.l. Probing beneath the submerged shelf suggests that the base extends to a maximum of 1 m below sea-level.

These deposits have been radiometrically dated as older than 50 000 years (Orme 1973). This, together with their elevation and geomorphic situation, suggests deposition during the Eemian high stand concomitant with plantation of the barrier terraces. The lithology and faunal content point to an unrestricted, high energy shallow marine situation in close proximity to the shore. Sea-level was at least 3 m above the present, and the water temperature possibly a few degrees warmer. It appears that False Bay was at this time a marine embayment with Hell's Gate opening directly to the sea. This would have been contemporaneous with one of the stages of bevelling of the barrier sandstones to seaward. These at this stage would have resembled some of the shallowly submerged 'reefs' off the present-day Natal coast, e.g. Aliwal Shoal and Glenton Reef. Living corals were restricted to areas of free circulation in the vicinity of Hell's Gate, and have not been encountered as fossils in those areas of False Bay which would have been very sheltered or periodically diluted by fresh water inflow.

The upper surface of the limestone slopes gently eastward (Fig. 8) and was possibly wave-planed. This was very likely a consequence of the Eem sea-level oscillations postulated above. On the other hand the surface may have been eroded during a Holocene transgression above the present sea-level. This is believed to be unlikely, however, in view of the apparent antiquity of some of the sands which overlap the landward margins of the limestone surface.

The approximate position of the Hluhluwe River outlet at this stage was probably in the vicinity of a patch of fluviatile or estuarine conglomerate some 2 m a.s.l. which is situated 2 km south-west of the present mouth.

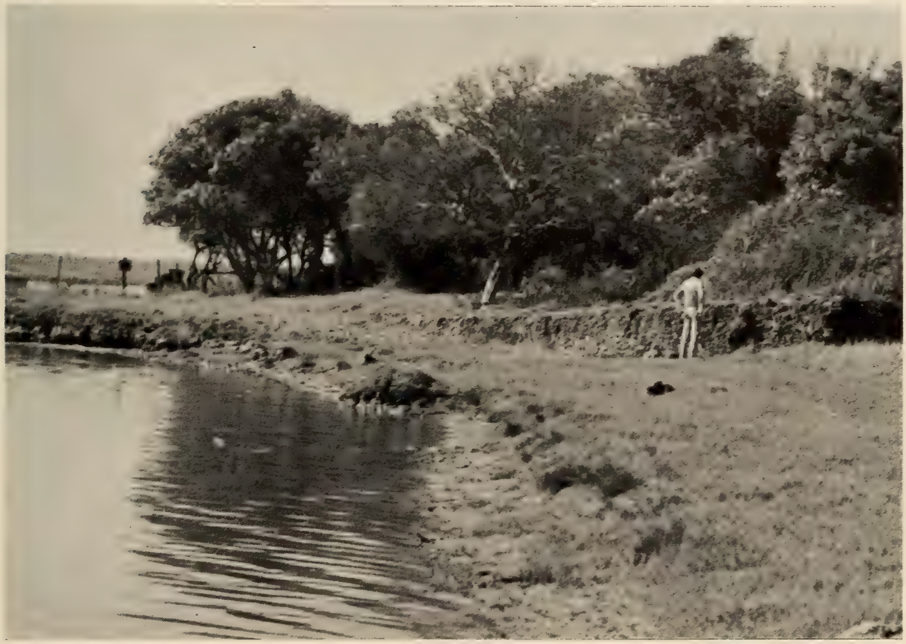

Fig. 8. Fossiliferous limestone at Lister's Point displaying eastward inclined surface.

SANDS OF THE COASTAL PLAIN

Several distinct varieties of unconsolidated sand mantle the coastal plain. Prominent north-south trending dune ridges consist largely of homogeneous red sand with pebbles and boulders towards the base. Six dune cordons, decreasing in age from west to east, have been mapped by Davies (pers. comm.).

A thick basal boulder bed occurs in the lowermost parts of the western cordons, e.g. at Bushlands Halt inland of the present study area. This is replaced eastward by scattered pebble bands at all elevations. A kilometre inland from Fanies Island Rest Camp pebbly coarse-grained sand attains a maximum thickness of 8 m. Heavy mineral laminae, containing up to 60 per cent zircon, rutile, magnetite, garnet and ilmenite, occur interlayered with quartz sand, which itself contains prominent textural banding. Pebbly coarse-grained beds 1–15 cm thick alternate with finer material in approximately the same proportion. These layers commonly display opposed (herringbone) cross-lamination. The pebbles are discoidal and of physically resistant lithologies, mainly vein quartz and quartzite. Further south near Charters Creek and in the Makakatana plantation area are similar deposits displaying low angle cross-bedding of variable azimuth.

These deposits are interpreted as of estuarine or shore zone origin, with indications of tidal reversal in flow. The presence of numerous westward inclined cross-beds precludes a normal fluviatile origin. The moderately mature composition and texture and the predominantly discoidal pebble shape suggest energetic processes with shape-sorting such as occurs on beaches or estuarine shoals.

The homogeneous red sand, which in most dune ridges overlies the boulder and pebble bearing deposits, has a median diameter in the fine-grained sand range and displays little regional variation in texture. Subangular to rounded quartz grains make up between 70 and 95 per cent. The heavy mineral content decreases eastward from a maximum of 8 per cent near Bushlands. In most samples clays constitute between 6 and 18 per cent, occasionally more. These appear to have originated by the kaolonization of feldspar, which is almost entirely absent. The red sand has a maximum thickness of 50 m immediately to the west of False Bay.

The innermost dune ridge, which passes through Hluhluwe village, is probably related to a very high early Pleistocene sea-level. The dune bases become progressively lower eastward concomitant with an increase in topographic relief and dune continuity. This is suggestive of decreasing antiquity, a conclusion which is supported by east-west differences in soil profiles. Indurated ferruginous zones, a product of advanced podsolisation, are well developed in the west. Although present 4 km inland from St Lucia Estuary this soil horizon has not been recognized seaward of Lake St Lucia.

The red sands of the dune ridges are attributed to aeolian processes which accompanied marine regressions. Together with the coarser estuarine or beach deposits at the base each probably constitutes a transgressive-regressive couplet, but the details are masked by advanced diagenesis, which has destroyed most primary structures, plus the obscuring effects of younger sands and dense vegetation.

Very fine-grained light coloured sand is intermittently exposed in a dune ridge adjacent to the western shores of Lake St Lucia and The Narrows. It rests on the Cretaceous at an elevation of 7–12 m and varies between 3 and 9 m in thickness. It is abruptly overlain by pebbly coarse-grained sands. Over 90 per cent of the sand is quartz with about 8 per cent calcite. It is well sorted, and unlike other sands in the area, displays marked positive skewness. This, in combination with other textural and compositional attributes, is suggestive of deposition by wind. An absence of internal structures and the weathering characteristics both resemble loess (Hobday 1965).

The coastal plain is veneered with coversands which are generally between 0,5 and 3 m thick. Some have undoubtedly been derived by leaching of red sands, as evidenced by white sand tongues which extend down into the red sand. There is nevertheless textural evidence of local redistribution, probably during Holocene times. Ventifacts have been recovered from this deposit at the top of a quarry to the west of Fanies Island Rest Camp.

Near Charters Creek a discontinuous thin layer of reworked hardpan is encountered between the red sand and overlying light grey sand. This gravel layer confirms that the upper sands are not simply the leached counterpart of the red sands but are substantially younger. This is further supported by marked textural contrasts. The median grain size of the coversands coincides closely with the homogeneous red sands, but some samples are slightly better sorted (Hobday 1965).

Low dunes and hummocky topography are present over much of the eastern half of the coastal plain. These are quite distinct from the larger red sand ridges from which they have been derived by local deflation. A north-south alignment is once more evident but is less consistent. Augering reveals that these dunes consist entirely of Holocene coversands.

LAKE ST LUCIA CORES

A coring programme conducted by the Provincial Roads Department at the request of Mr T. Blok, engineer in charge of St Lucia Reclamation, established that sediment thicknesses are considerably greater than had previously been suspected (Kriel 1965). Seven continuous cores, extending from the sediment-water interface to Cretaceous bedrock, were obtained from a floating rig (Fig. 9). Their locations are indicated in Figure 1. The depth to bedrock and the salient lithological and faunal characteristics are depicted in Figure 10. This diagram illustrates the variability in thickness of the Quaternary fill, ranging from a minimum of 7,8 m to a maximum of 33,5 m. Figure 10 also demonstrates a lack of stratigraphic similarity between the various cores apart from a general tendency for the coarser sediment grades to occur in the lower parts. Carbonaceous mud and silt, such as dominate much of the present bed of the lake, constitute the bulk of the upper part of the cores.

The foraminiferal content of core samples taken at 50–100 cm intervals has been analysed by Phleger (in press). A number of carbonaceous samples

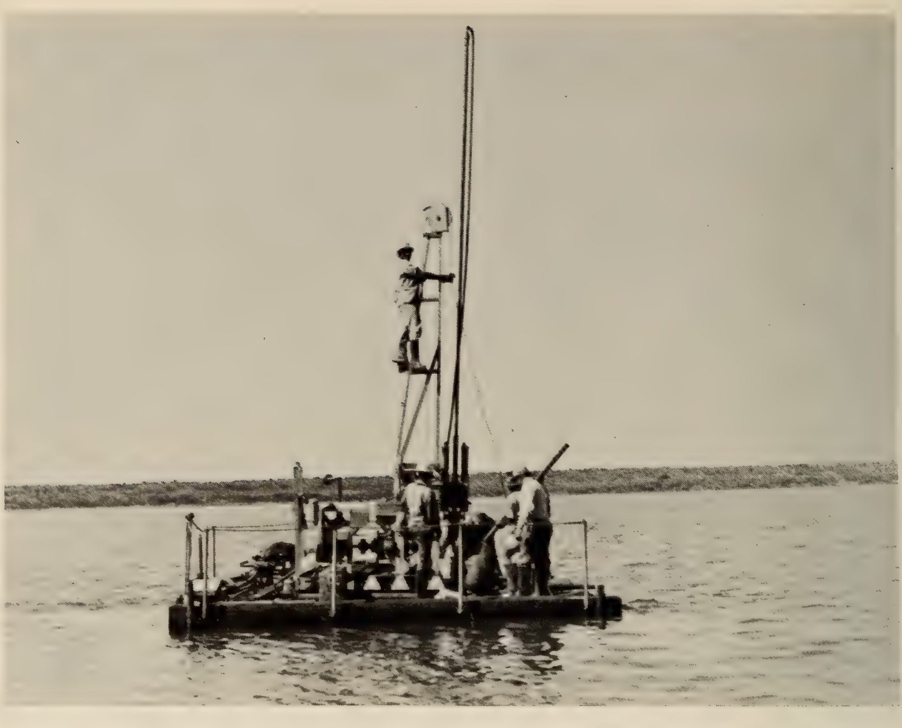

Fig. 9. Floating rig utilized to obtain deep sediment cores in operation in False Bay.

are being processed by J. Vogel of the Council for Scientific and Industrial Research for radiocarbon age determination. The preliminary findings, together with those reported by Kriel (1965), indicate a Holocene age apart from the deeper parts of some cores which extend into the late Pleistocene.

Core 1 from northern False Bay extended to a depth of 33,5 m. Below a depth of 19 m silt and shelly sand predominate and contain a variety of molluscs, some of which are of marine affinity (R. N. Kilburn, pers. comm.). This accords with the findings of Phleger (in press) who detected foraminiferal evidence of marine conditions, with unrestricted access to oceanic water at depths of 21,5 m and at the bottom of the core. Sedimentological evidence for high energy processes comes from 50 cm of reworked Cretaceous at the base, but this is overlain by deposits of sand and mud suggesting rapid reduction in energy as a result of deepening and the sheltering effect of a barrier.

Bioturbated mud containing broken, thin-shelled molluscs makes up all but the basal 3 m of Core 2. Phleger (in press) reports the presence of gypsum crystals at depths of between 18,5 and 25,5 m. This indicates that even during the early Holocene there were periods of intense desiccation initiated by effective lagoonal confinement and lack of appreciable inflow of fresh water. Phleger notes foraminiferal indications of marine conditions just above transgressive white sands at the base of the core, and at depths of 4,5–5 m.

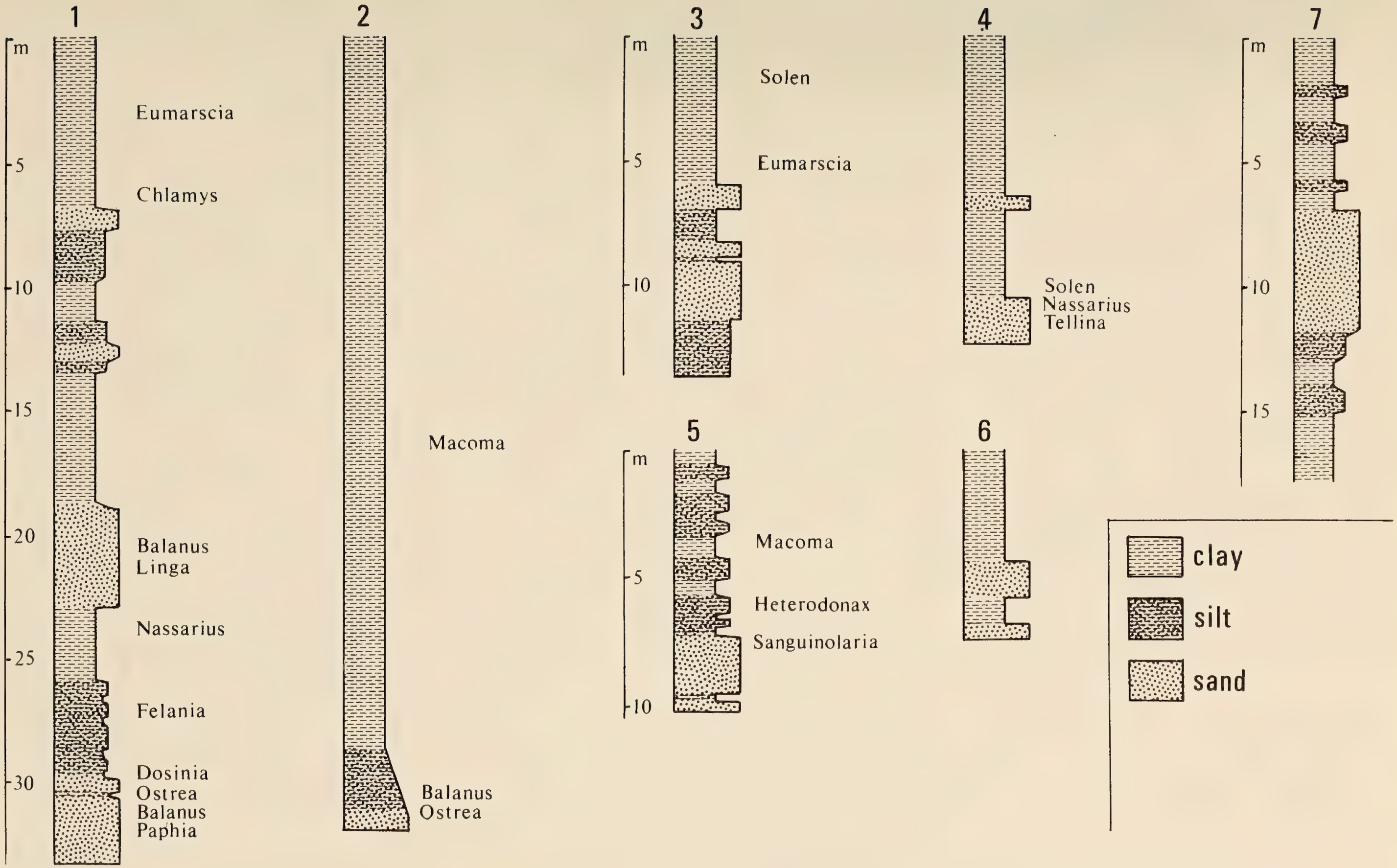

Fig. 10. Schematic representation of lake cores indicating dominant grain size and generalized distribution of commonly encountered macrofaunal genera.

Core 3 struck Cretaceous bed-rock at a depth of 13,7 m. Between 10 m and the base are poorly sorted sand and oxidized silt containing calcareous and ferruginous concretions. These are interpreted as fluviatile deposits. They are overlain by 2,5 m of sand containing broken shells, apparently of estuarine origin. Above these are typical lagoonal muds with abundant *Eumarscia pauperscula* giving way upward to *Solen corneus*. Scattered sand-size quartz grains with a red oxide coating were probably blown in from the Pleistocene red sand cordons.

The basal sediments of Core 4, situated in the north-east, consist of 20 cm of aeolian sand. This is followed by 1,5 m of very shelly sand with shallow water estuarine or lagoonal macrofauna such as *Solen* and *Balanus*. Phleger (in press) finds the upper parts of the core to be characterized by high production of foraminifera, indicating a plentiful nutrient supply by tidal incursions or river inflow.

Core 5 to the south of Bird Island indicates a thin basal layer of aeolian sand. This is followed by 40 cm of relatively poorly sorted sand containing articulated bivalves suggestive of a sheltered environment. The remainder of the core consists of rapid alternations of silt and mud, a textural contrast which characterizes the floor of the Lake in this area at the present day. The included fauna are essentially estuarine or lagoonal forms.

Core 6 in the southern portion of the Lake struck bed-rock at a comparatively shallow depth of 7,8 m. White sand at the base is overlain by 50 cm of high oxidized medium-grained red sand identical to the wind-blown red dune deposits of the modern coastal plain. A metre of estuarine mud which overlies the red sand is followed by fine-grained brown sand with *Solen* and mud clasts. The latter are indicative of periods of subaerial exposure followed by inundation such as occur in a tidal mudflat, or in a non-tidal situation such as Lake St Lucia today where the level is subject to fluctuation. The uppermost deposits consist of 4,5 m of black mud.

The Narrows (Core 7) display a sequence which is conspicuously different from any other. Whereas shells are generally absent finely disseminated vegetal detritus is common throughout. Phleger (in press) records evidence in the presence of *Trochammina* sp. of a marine marsh environment above a depth of 15 m. Mud at a depth of 15 m coarsens upward through silt with ferruginous concretions into silty sand, a typical lacustrine or 'bay fill' pattern produced by lake shore encroachment over lake floor muds. Below a level of 15 m Phleger finds a complete absence of foraminifera, which is suggestive of a freshwater marsh deposit.

A second core was only partially retrieved from a position very near to Core 7 but slightly further seaward. The succession was generally similar apart from a well-defined layer of beach sand at a depth 7,7–12 m. Its position within a marine marsh setting is suggestive of washover processes whereby beach-barrier sand is transported landward over back-barrier salt marsh during storms.

DISCUSSION AND CONCLUSIONS

Despite controversy over the degree and timing of Quaternary sea-level changes it is generally accepted that early Pleistocene levels were considerably higher than at present. Because glacio-eustatic oscillations were superimposed on this non-glacial regression, retreat of the sea from the Zululand coastal plain was undoubtedly erratic and accompanied by several reversals. North-south aligned dune ridges, whose positions are related to former shorelines, are conspicuously younger eastward. Many of these ridges comprise a basal transgressive beach deposit overlain by aeolian sands. Unfortunately the details of these early to middle Pleistocene events have for the most part been masked by reworking, vegetation and advanced diagenesis.

The drainage pattern was profoundly influenced by these dune ridges. The Mzinene River was deflected first northward and then southward to unite with the Nyalazi and Hluhluwe Rivers, which had been confined behind the same ridge. River valleys became deeply entrenched during stages of sea-level lowering. Northern False Bay and Hell's Gate were both incised to depths greater than 30 m. Shorelines corresponding to these low stands were situated near the outer edge of the continental shelf. The combined discharge through Hell's Gate probably joined with the Mkuze River to extend across the emergent shelf and erode the deep canyon which is present off Leven Point. Hopefully further coring in the northern lake will document this hypothetical confluence.

Unlike most barrier–lagoon systems which were initiated in response to a deceleration in the rate of sea-level rise during the period approximately 7 000 to 5 000 years ago (Curray 1969; Phleger 1969), the St Lucia barrier had an earlier origin. A spine of aeolian sandstones, thought to be related to the penultimate or Saalian glaciation, was truncated during the Eem transgression. There were probably three distinct peaks of sea-level advance during which beach and nearshore sand and gravel accumulated. The two intervening stadials are marked by a karst erosion surface and a younger aeolian sandstone respectively.

Planation and inundation of the ancestral barrier sandstones during the sea-level maxima would have permitted free marine circulation in the area now occupied by Lake St Lucia. Hell's Gate opened directly to the sea, with small islands protruding above the barrier, which otherwise was shallowly submergent and breached by a number of channels. The western shores of Lake St Lucia were sea-cliffs at this time, thus possibly accounting for their present linearity. Unimpeded oceanic incursion in those areas of False Bay adjacent to Hell's Gate permitted the growth of coral reefs. A variety of molluscs flourished and accumulated in situ as oyster beds and as bioclastic deposits. Other commonly occurring organisms were brachiopods, barnacles, sponges and echinoderms.

During the last glacial retreat the bulk of the earlier valley-fill deposits were eroded. Onshore winds crossing the emergent shelf blew sand against the sandstone barrier core. A prominent submarine ridge near the outer margin of the continental shelf may be a relict barrier marking the maximum extent of the Weichsel regression. Lower ridges to landward possibly represent beach ridges developed and subsequently flooded during the Flandrian transgression.

Sedimentological and faunal evidence from the Lake St Lucia cores indicates that lagoonal confinement was established at an early stage during the post-glacial transgression. Nevertheless, marine conditions were periodically reintroduced by the breaching of outlets. Progressive reduction of river gradients resulted in the blocking of river mouths in the north, presumably by littoral drift followed by dune formation. Only the Mfolozi River was sufficiently large to maintain an exit.

The combined waters of the northern rivers became impounded behind the barrier thus formed. As the lagoon level rose the margins overflowed the adjacent depressions between the coastal barrier and older ridges inland. This ancestral Lake St Lucia system occupied an area of 1 165 km^2 (Orme 1973), covering the existing Mkuze swamps. Between St Lucia and the drowned Mfolozi valley to the south was a relatively shallow spillway where the waters were deflected over older alluvium to the only outlet at the mouth of the Mfolozi.

Subsequent changes in the configuration of the Lake St Lucia system were accomplished by delta infilling, segmentation, swamp encroachment and local shoreline erosion (Hobday 1965; Orme 1973). Pronounced accumulation of mud in the immediate vicinity of rivers entering the Lake is probably due to flocculation of clays in saline water. As noted by Phleger (1969) a marked reduction in salinity during flood stages allows clay to become more widely distributed over a lagoon. At the present day the entire floor of the Lake is above effective wave base. As a consequence wind-induced waves and associated currents are the most effective sediment transport mechanisms.

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AEOLIANITE: AUSTRALIAN AND SOUTH AFRICAN DEPOSITS COMPARED

By

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(With 5 figures)

ABSTRACT

A comparison of Australian and South African Pleistocene consolidated beach and dune deposits is presented. Their distribution, largely south of 30°S on former marine platforms, seawards of deeply weathered erosion bevels and extending below present sea-level, is discussed. Their spatial relationships both with underlying bedrock and with other similar deposits are considered. It is shown that whereas on a coast of submergence aeolianite deposits of different ages will be superimposed, in areas of emergence the strandlines will be spatially separated. In the Lower Southeast of South Australia where this is the case, the ridge complexes have been shown to conceal breaks of slope in the underlying limestone bedrock. The latter are attributed to transgressive marine erosion. It is postulated that similar breaks of slope will be found to underlie South African aeolianite deposits. Furthermore it is postulated that erosion of the underlying limestone provided a source of calcium carbonate for subsequent lithification of the backshore beach and dune ridges.

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INTRODUCTION

Consolidated calcarenite dune or beach material, generally termed aeolianite* in South Africa, is a widespread Cainozoic legacy along subtropical coasts (Fairbridge 1968). As relict strandline material it offers considerable potential for the elucidation of Cainozoic coastal fluctuations. In South Africa, however, specific studies of these deposits have, until recently, been neglected. By contrast, in Australia aeolianite deposits have attracted considerable attention as a potential basis for Quaternary chronologies (Bird 1960; Gill 1967; Hossfeld 1950; Sprigg 1952; *et al.*). Nevertheless interpretation of the results is fraught with difficulty.

Through a comparison of the better documented Australian occurrences with their South African counterparts, this paper focuses attention on aspects of aeolianite distribution and spatial relationships.

*Although cemented calcareous beach sandstones, properly termed calcarenites, are dominantly of aeolian origin, the presence of cross-bedded sands incorporating shell bands suggests that the term aeolianite is not strictly correct. For the purpose of this paper the term will, however, be retained.

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Ann S. Afr. Mus. **71**, 1976: 115–124, 5 figs.

Aeolianite consists of consolidated beach and dune sands distinct from currently forming beach rock. Most aeolianite deposits are of considerable thickness, exhibit pronounced cross-bedding and are Pleistocence to Holocene in age. Being largely backshore deposits, they mark former strandlines. The beach and dune sands have been consolidated to varying degrees by calcium carbonate. Lithification therefore implies a considerable amount of calcium carbonate grains or comminuted shells in the original sands, a long period of leaching to cement the core material with concomitant formation of overlying dominantly quartzose sands. The current absence of the latter in association with the aeolianite further implies that the aeolianite deposits must now be considerably diminished in volume. Where several phases of aeolianite deposition have occurred, it is likely that the leached overlying sands have been incorporated into the later deposits. The degree of lithification depends partly on age but also apparently on exposure. Thus resistant aeolianite frequently outcrops along eroding cliffs and on the present beach, lithification being associated with spray wetting.

AEOLIANITE DISTRIBUTION

Australian aeolianite deposits are widely distributed along the south-eastern coasts from Westernport Bay, on the Bass Strait islands and northern Tasmania to Eyre Peninsula. The red silicious dunes of the east coast are, however, very different and they contain no aeolianite core (Bird, E. C. F. & Thom, B. pers. comm.). Aeolianite deposits are also found along the western coast between Cape Leewin and North West Cape where they rest on the Coastal Limestones, in origin also aeolianite (Fig. 1).

Aeolianite is also widespread along the South African coastline between Saldanha Bay and East London. More recently the red sands of the coastal fringe between the Transkei and Zululand have been recognized as similar in origin but now deeply weathered (McCarthy 1967; Maud 1968). A distinction

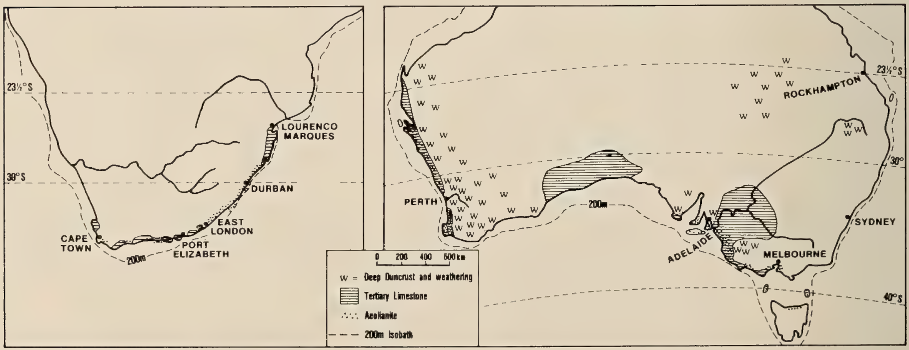

Fig. 1. The distribution of Australia and South African aeolianite deposits in relation to Tertiary limestones and deep weathering profiles.

must be drawn between the Berea Red Sands, a weathering product of the aeolianite Pliocene Bluff Beds, and the high red dunes which have a core of aeolianite material (Maud 1968). Although at least three distinct phases of aeolianite formation have been reported from widely separated localities (Martin 1962; Maud 1968; McCarthy 1967), detailed analyses of specific localities have been largely neglected.

Comparison of the distribution of aeolianite deposits in Australia and South Africa highlights certain similarities (Fig. 1). In both Australia and South Africa, aeolianite deposits are most common south of latitude 30°S. The northward extension towards the Tropic of Capricorn of the South African red weathered aeolianite dunes has no counterpart in Australia although recently weathered aeolianite has been reported from a rainshadow coast near Townsville (Hopley 1971). The absence of relict aeolianite in the tropics generally may therefore be a function of leaching efficiency rather than of original deposition patterns.

In both countries aeolianite deposits rest on marine benches and extend below sea-level. The present coastline generally truncates the alignment of the aeolianite ridges, indicating their emplacement under conditions of low sea-level. Such truncation is clearly seen between George and Knysna (Fig. 2), at Kenton-on-Sea (Fig. 3) and in the high dunes of Zululand. The Aliwal Shoal, and probably the Protea Bank also, are seaward extensions of the Bluff Beds which have been proved to a depth of —100 m on The Bluff itself (McCarthy 1967). The Wilderness aeolianite ridges have been mapped to a

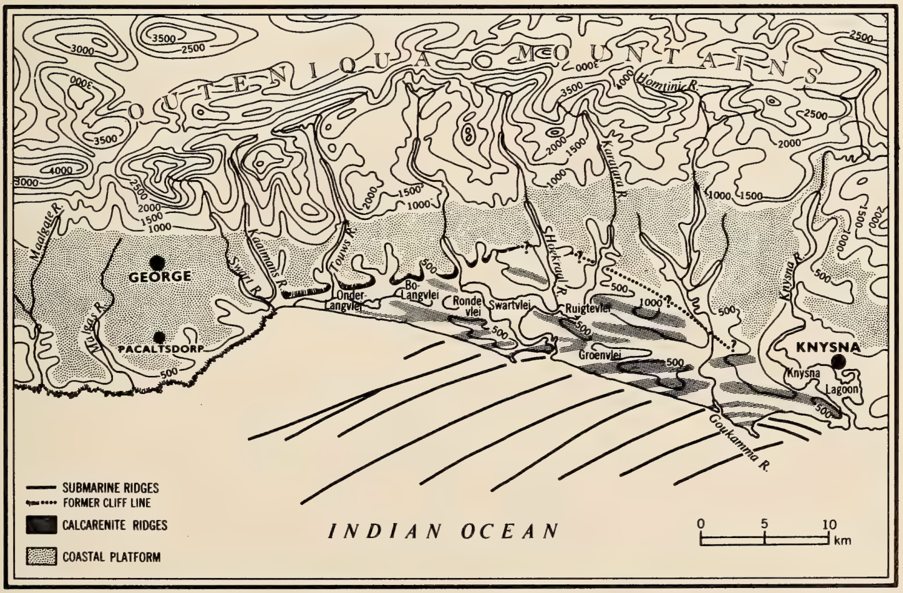

Fig. 2. Aeolianite ridges in the George–Knysna embayment (after Tyson 1971).

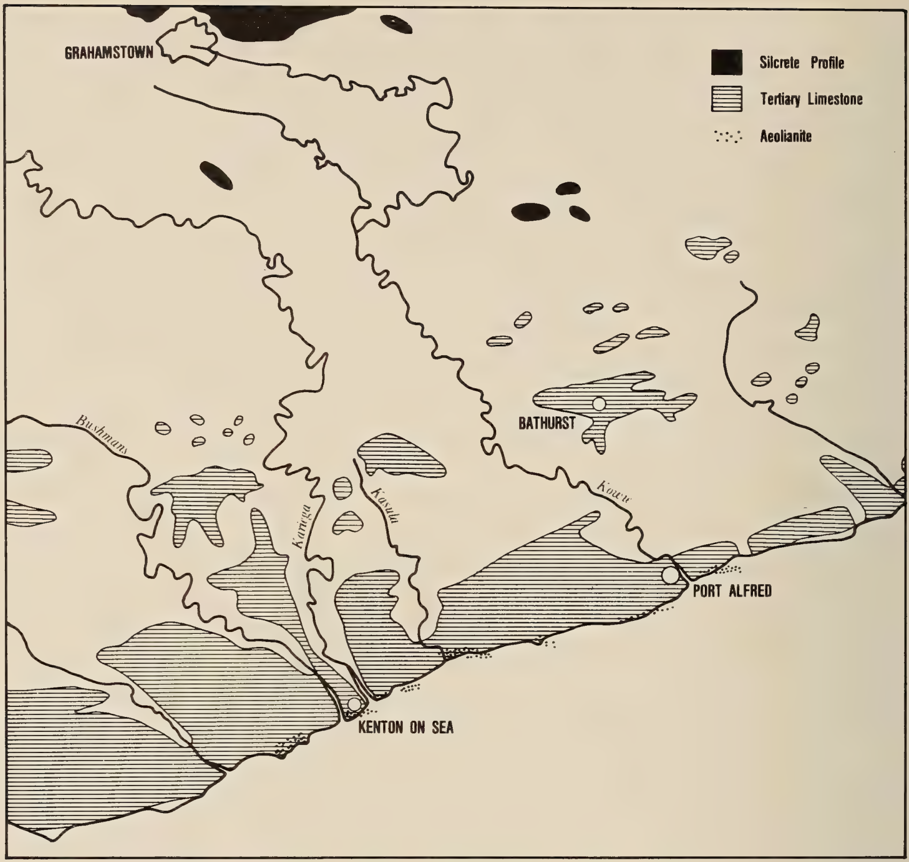

Fig. 3. Aeolianite deposits of Eastern Cape Province.

depth of —55 m and the reefs of Plettenberg Bay are also aeolianite in origin. Such discordance of Pleistocene and modern shorelines is equally true of Australia. In Western Australia Rottnest Island off Perth is formed of aeolianite. Soil profiles developed on aeolianite and buried by later aeolianite deposition occur below mean sea-level at Sorrento in Victoria and the base of the youngest ridge in the Lower Southeast of South Australia lies at —11 m on the seaward side (Fig. 4).

A second feature is the close juxtaposition of aeolianite deposits and mid-Tertiary erosion bevels carrying relict deeply weathered soils (Fig. 1). The emergent beach ridge sequence of the Lower Southeast of South Australia commences immediately shorewards of the laterite capped Dundas Tablelands (Fig. 4). The West Australian limestones abut on to the laterite-capped Darling Ranges peneplain. In South Africa the George–Knysna ridges lie seawards of the laterite-capped Coastal Platform (Fig. 2) and the Kenton-on-Sea aeolianites have the Grahamstown silcrete profiles inland of them (Fig. 3).

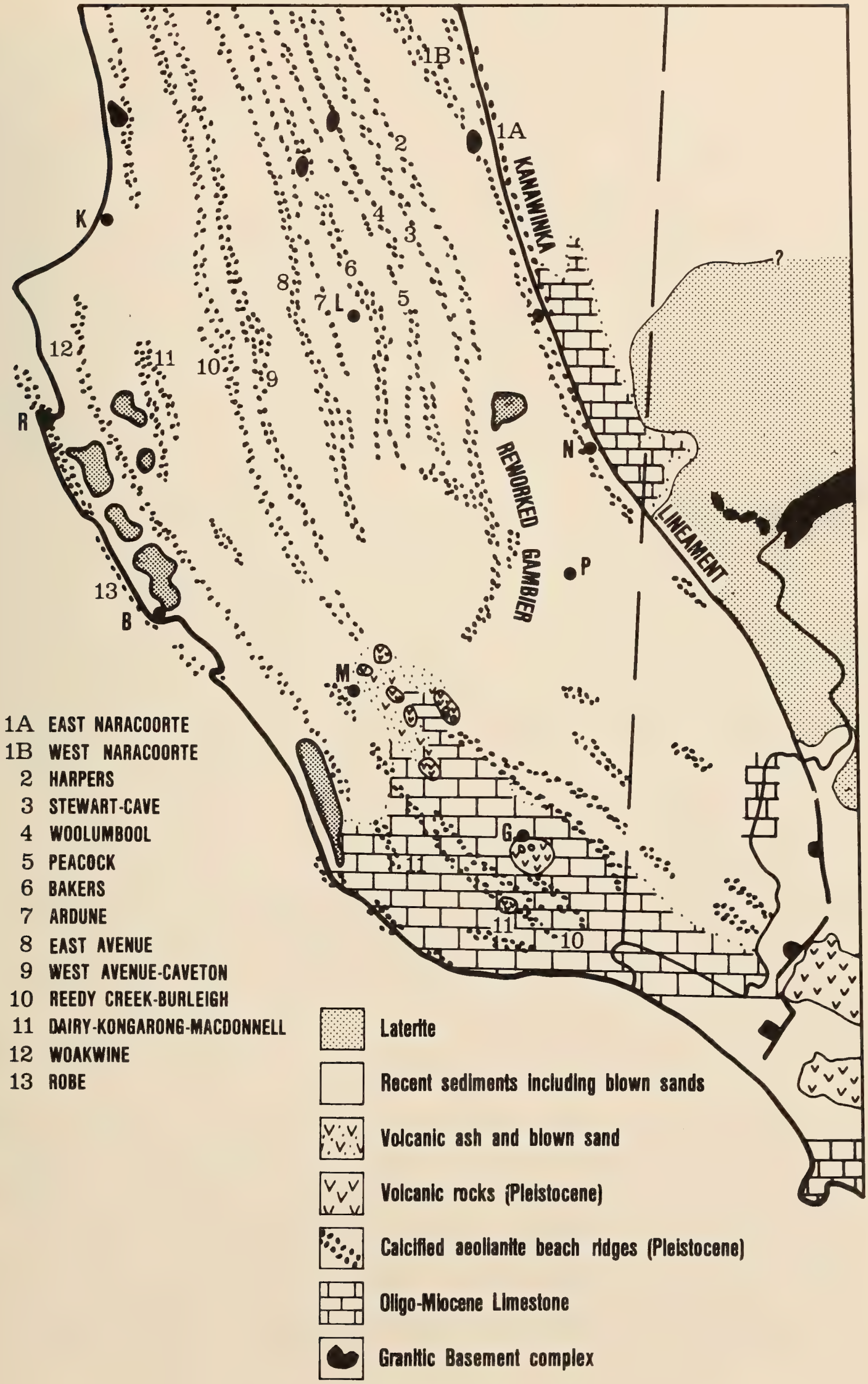

Fig. 4. Aeolianite beach ridges in the Lower Southeast of South Australia.

In every case aeolianite covers marine benches immediately below the level of the weathered Tertiary bevel. Frequently, it rests on marine limestones, deposited contemporaneously seawards of this planated land surface. In the eastern Cape these marine deposits are believed to overlie three marine-cut benches (Dingle 1971; Ruddock 1968; Siesser 1972), and are typical regressive marine deposition facies. However, the degree of diagenesis and in particular of recrystallization indicates that three transgressions and regressions were involved and that reworking of the marine limestones and superimposed aeolianite has destroyed much of the earlier material (Siesser 1972). The Coastal Limestones of Western Australia have also been so modified that little trace of cross-bedding remains and the recrystallized limestons are capable of hosting extensive cave systems. This alteration is attributed to marine transgression which has bevelled and eroded the deposit. In many respects the much modified West Australian Coastal Limestones bear a close resemblance to the Cainozoic Limestones of South Africa. Recently the term Coastal Limestone has been proposed to include the Dorcasia Limestones of Saldanha Bay, the Bredasdorp Beds and the Alexandria Formation (Siesser 1972). All these limestones consist of marine beds overlain by redistributed and altered aeolianite. In places younger, recognizable, cross-bedded, calcareous sandstone aeolianite rests on top of the altered Cape Coastal Limestones, just as it does in Western Australia.

The close association of cross-bedded aeolianite and underlying limestone, whether of aeolian or marine provenance, suggests that their juxtaposition is not fortuitous. Destruction of the limestone by bevelling during a transgression would provide a source of calcareous sand to add to beach quartzose material and thus enable lithification of the aeolianite during the subsequent regression. In south-eastern South Australia the bedrock is Miocene bryozoal limestone and even the present beach sands are rich in calcium carbonate. However, in many other aeolianite localities present-day beach sands are so low in calcium carbonate that lithification is hard to envisage. It is suggested that in such localities the Tertiary limestones have now been totally eroded and that the aeolianite is a relict deposit determined by the former presence of calcareous bedrock. The patchy distribution of Tertiary limestones in South Africa lends credence to this suggestion.

SPATIAL RELATIONSHIPS

Elucidation of the relationships of different aeolianite deposits to each other and to the underlying bedrock is dependent on precise and detailed mapping. The tendency for aeolianite occurrences to be superimposed, juxtaposed and elided and their association with recent blown sands of the present coastline have hampered the collection of comprehensive data.

Spatially distinct aeolianite ridges representing former strandlines have been preserved only in areas of Pleistocene emergence. The Lower Southeast of South Australia provides one of the best sequences, but the series associated with the George–Knysna embayment is similar. Both areas have attracted considerable attention (Sprigg 1952; Hossfeld 1950; Martin 1962; Tyson 1971).

Where subsidence was current, aeolianite deposits are superimposed with intercalated soil profiles. Such sequences are well seen at Sorrento, Victoria (Bird 1972) and along the coast north of Perth, Western Australia. The Zululand red dunes with an aeolianite core are superimposed on Berea Red Sands, but the supposed superposition at The Bluff, Durban, has been shown to be a raised beach deposit (McCarthy 1967). Subsiding coasts have caused submergence and partial destruction of aeolianite surface morphology and its burial under more recent deposits. It seems probable that this has been the case in the Eastern Cape.

The ubiquity of these inter-ridge recent deposits conceals in most cases the contact of aeolianite and bedrock, so that the ridges have been presumed to rest on gently shelving marine benches (Davies 1971). Recent studies have, however, indicated that this may not be true. In the Durban area aeolianite deposits have been shown to abut on three distinct breaks of slope (Maud 1968). Analysis of the surface topography of the Miocene Limestone, a karst host rock, in the Lower Southeast of South Australia using a close borehole data grid has produced information of relevance in this respect (Marker 1975). There aeolianite beach ridges abut on and cover cliffs in the underlying bedrock (Fig. 5). Each distinct aeolianite ridge series therefore records a marine transgression when the step was cut and a regression when the sands were blown from the exposed shore platform against the cliff. The borehole plot suggests that certain strandlines overlie pronounced cliffs and these can be interpreted as representing major periods of stillstands. The East Naracoorte beach abuts against the early Pleistocene or late Pliocene Kanawinka cliff. The Mingbool, Compton, Caveton, Allendale and Robe coastlines, the latter partly buried by more recent sands at C. Northumberland, are also dominant. In some cases raised beach pebble deposits occur at the same altitudes to confirm the borehole evidence. The Lower Southeast of South Australia has a sequence of strandlines extending in time from at least early Pleistocene to ± 8 000 years B.P. at Robe. The central Caveton complex has yielded C^{14} dates exceeding 35 000 years B.P. (Blackburn 1966) but on geomorphological grounds is considered more likely to date from about 135 000 years B.P. (Chappell, J., pers. comm.).

In the George–Knysna embayment a series of four strandlines have been identified (Martin 1962). However, it appears likely that at least twelve such strandlines exist. The earliest aeolianite material has recently been related to the 100 m bevel, the second to the 60 m bevel, the third to the 18 m bevel and the fourth to the 8 m bevel (Butzer & Helgren 1972). However, these workers did not recognize the greater number of ridge complexes. It appears, therefore, well established that aeolianite ridges are associated with marine cliffing. The implication is that whenever contacts between aeolianite and bedrock are

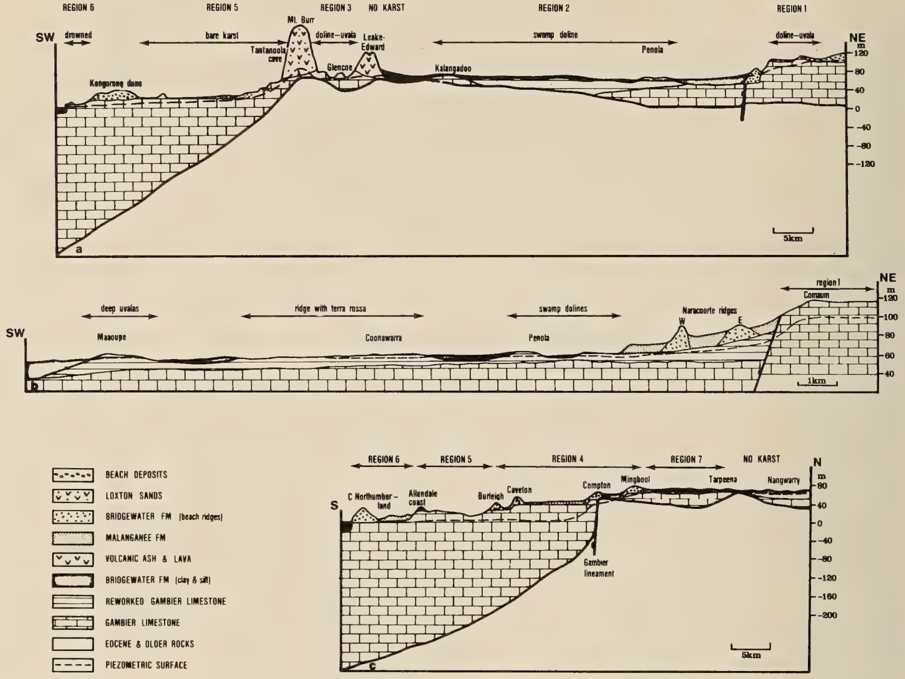

Fig. 5. Sections across the Lower Southeast of South Australia to show the association of aeolianite beach ridges with bedrock, breaks of slope (compiled from borehole data).

recorded it is essential to establish whether the site lies landwards or seawards of the deposit.

On the Eastern Cape coast between Kwaaihoek and Kleinemonde aeolianite outcrops in cliffs, on the beach and extends seawards in a north-easterly direction as reefs (Fig. 3). The base of the deposit is only rarely exposed. In the Bushman and Kariega estuaries aeolianite rests on and incorporates beach cobbles at −1 to −2 m below mean sea-level. Since this aeolianite extends seawards, this altitude can be taken to be the landward altitude of the marine bench that has been incised. At Port Alfred another aeolianite rests on Cape System bedrock at an altitude of approximately 4 m (Mountain 1962). Inland from the coastal aeolianite at Kenton-on-Sea a marine cliff is cut into the Coastal Limestone with a summit bevel at 60 m, which is overlain by another, presumably older aeolianite. Further aeolianite deposits mapped with the Coastal Limestones overlie other breaks of slope inland. However, even if the coastal outcrops alone are considered, it is apparent that remnants of a series of ridges exist (Fig. 3).

CONCLUSIONS

Comparison of Australian and South African deposits has emphasized certain salient facts. Aeolianite deposits record former, probably Pleistocene, strandline positions. The deposits appear to be located over marine-cut breaks of slope. They are regression deposits, subsequent to the transgressions that eroded underlying calcareous bedrock, thus providing both calcium carbonate in sufficient quantity for lithification and cliff loci for sand deposition. The marine bedrock seems to have been laid down contemporaneously with deep weathering of the mid-Tertiary planation surfaces. The degree of diagenesis and alteration of early aeolianite deposits appears to be the consequence of marine submergence and planation. Such altered deposits retain nothing of their original surface morphology and little of their structural morphology, therefore their value for elucidation of a Quaternary chronology is minimized. The degree of lithification of later aeolianite deposits is a function of age and/or exposure to sea-spray wetting. Although hard aeolianite occurs in shore locations it may be contemporaneous with less consolidated inland deposits. In general the older the aeolianite, the greater the degree of lithification. Aeolianite deposits have a neglected potential for the elucidation of Cainozoic coastal chronologies.

ACKNOWLEDGEMENT

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LATE QUATERNARY COLLUVIAL DEPOSITS (PROGRESS REPORT)

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(With 3 figures and 2 tables)

ABSTRACT

At the northern entrance of the Daspoort tunnel in Pretoria a massive gravel deposit is exposed at the junction of the pediment and hillslope. On the upper section of the pediment the gravel is discordantly overlain by red sand beds, and the top of the gravel layer bears a ferricrete horizon. Lower down on the pediment, excavations reveal colluvial sand beds, representing two major stages of deposition. The lower sand beds, bearing iron concretions, apparently constitute the downslope facies of the gravel layer. It is proposed that the gravel deposit and its extension is a sheet-flow deposit dating from the last Pleistocene pluvial period, and the upper, red sand a lower energy sheet-flow deposit dating from an Holocene pluvial phase of lesser intensity.

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GRAVEL DEPOSIT

At the northern entrance of the Daspoort tunnel in Pretoria a massive, red (5YR4/6) colluvial gravel deposit, 6–7 m thick, is revealed at the foot of the Daspoort hillslope (1330 m; 25.44S). The deposit is composed of an assemblage of sub-angular quartzite and some vein-quartz fragments set in a matrix of finer gravel and fine-earth. The rock fragments and matrix are heavily iron-stained and iron-impregnated. The gravel deposit obliterated the original sharp knickpoint between pediment and hillslope and the present junction is a concave break of slope from 20° on the hillside to 3° on the upper pediment. Upwards the deposit pinches out against the hillside and downslope it also diminishes in thickness. The geological relationships are shown in Figure 1. The dip of the strata is about 28° and the deposit rests discordantly upon partly decomposed shale.

Coarse layering can be detected and five sub-phases of deposition may be distinguished, as borne out by analyses of samples. (See Fig. 2.)

All quantitative determinations quoted in this paper have been performed by J. H. Reynhardt (1975).

Layer A: Thickness 1 m; about one-third by volume composed of rock

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Ann. S. Afr. Mus. **71**, 1976: 125–132, 3 figs, 2 tables.

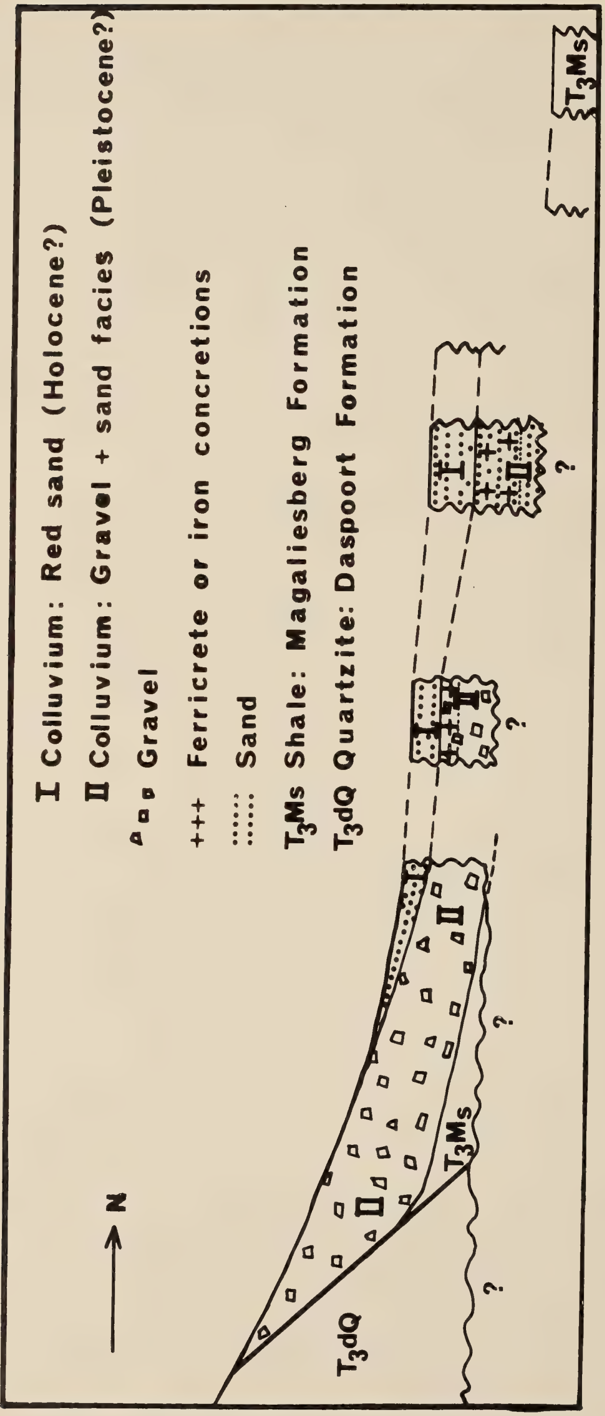
I Colluvium: Red sand (Holocene?)
II Colluvium: Gravel + sand facies (Pleistocene?)
Gravel
+++ Ferricrete or iron concretions
Sand
T_3Ms Shale: Magaliesberg Formation
T_3dQ Quartzite: Daspoort Formation
N
T_3dQ
T_3Ms
I
II
?

Fig. 1. Schematic section across the northern slope and pediment of the Daspoort range, Claremont, Pretoria.

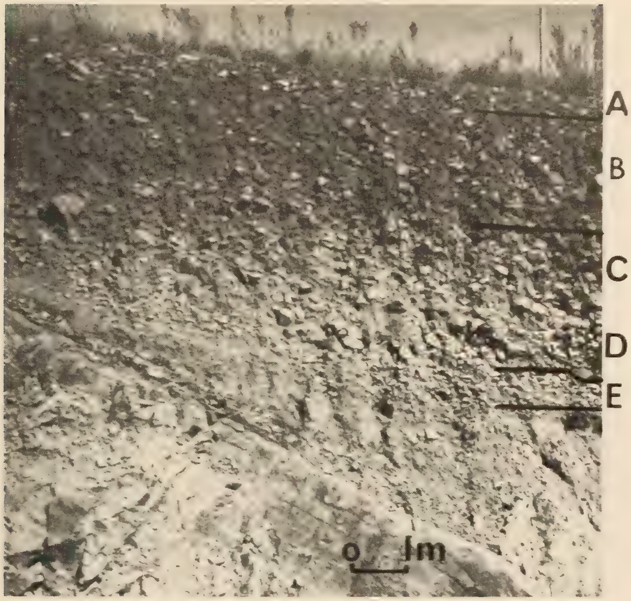

Fig. 2. Colluvial gravel deposit at the northern entrance of the Daspoort tunnel, Pretoria.

(quartzite) fragments, average long-axis 10 cm; loamy sand matrix; gradual transition to B.

Layer B: Thickness 2,5 m; about one-half by volume composed of rock fragments, average long-axis 12 cm; sandy loam matrix; clear transition to C.

Layers C and D: Thickness 2,5 m; about three-quarters by volume composed of rock fragments, average long-axis 15–16 cm; sandy clay loam matrix; quartzite fragments of up to 30 cm are quite frequent in these layers; abrupt boundary with E.

Layer E: Thickness 0,5 m; distinctive well-rounded, heavily patinated (some black) pebbles and cobbles, gravel size smaller than 10 cm.

Thus there is an increase in the coarseness of the gravel from top to bottom, layer E being the exception, and also an increase in gravel content.

The roundness of the gravel was determined according to the method described by Sames (1966: 127). Looking at the outline of the pebble the convex-shaped parts are measured and the total convex length expressed as a percentage of the whole circumference. According to the wear six roundness grades are distinguished by Sames; angular 0–10% rho; subangular: 15–25% rho; subrounded: 30–40% rho; rounded: 45–60% rho; well-rounded: 65–80% rho; extremely well-rounded: 85–100% rho. For layer A the average roundness is 33% rho and Standard Deviation 20% rho; for layer B the respective figures are 30% rho and 17% rho; for layer C, 26% rho and 12% rho; for layer D, 20% rho and 8% rho; for layer E, 56% rho and 33% rho. The gravel in layer E is significantly more rounded than the gravel from all other layers.

Mechanical analysis of the matrix material (< 2 mm) from the various layers shows a significant increase in clay content from top to bottom and a corresponding decrease in the sand fractions (see Table 1). This is probably due to a greater measure of weathered shale admixture during the earlier phases of deposition, the area of shale exposure having diminished as the deposit accumulated, or to better sorting as the slope on the pediment increased as a result of the progressive accumulation of sediment at the junction of the hillslope and pediment.

TABLE 1

Mechanical analysis of matrix material (< 2 mm) of the gravel deposit

Layer	*Sand* (%)	*Silt* (%)	*Clay* (%)
A	86	4	10
B	75	5	20
C	70	6	24
D	48	12	40
E	39	14	47

Heavy residue analysis shows a significant difference between layers D and E (see Table 2), the latter showing a greater degree of weathering.

To differentiate further between the various layers in the gravel deposit a cluster analysis was performed with the aid of a computer programme (see Davis 1973), using sixteen variables based on particle size distribution, gravel content, morphometric characteristics, and heavy mineral composition. The most significant boundary was found to be that between layers D and E (difference of 19 units), while the smallest difference was that between layers A and B (6 units). The difference between layers B and C was 9 units.

TABLE 2

Heavy residue analysis of gravel deposit

Layer	*Zircon/Tourmaline Ratio*	*Zircon/(Epidote + Pyroxene) Ratio*
A	5,0	0,6
B	4,7	0,6
C	4,0	0,4
D	5,0	0,4
E	4,0	0,9

From the combined analyses the conclusion may be drawn that a major lithologic discontinuity is present between layers D and E and subordinate discontinuities between layers A and B and between B and C.

The well-rounded, patinated gravel of layer E probably represents reworked residual rubble of more resistant components lying on the pre-existing surface and therefore reflects climatic conditions prevailing before the onset of colluviation. The residual character of this layer is further borne out by the higher degree of weathering of the matrix material as exemplified by the higher zircon/(epidote + pyroxene) ratio. The pyroxene most probably derives from the diabase intrusions in the quartzite.

In layer D there is a sudden increase in coarse quartzite fragments, and of much greater angularity, which would be indicative of high energy weathering and mass transport over a short distance so that little sorting could take place, as the relatively high percentage clay in the matrix seems to indicate. Upwards there had been a gradual decline in transport energy conditions, the deposition having taken place in phases, as minor discontinuities in the profile indicate.

RED SAND BEDS

Just below the break of slope a red sand layer commences, discordantly overlying the gravel deposit. From this and other exposures it can be observed that the red sand deposit, with increasing thickness, extends across the pediment surface, sloping about 2°, to a line about halfway the distance between the foot of the hillside and the lowest point (Modderspruit) in the longitudunal valley between the Daspoort and Magaliesberg ranges, where the sand deposit pinches out and weathered shale bedrock is exposed.

About one kilometre west of the tunnel entrance, on the upper section of the pediment, an excavation shows the same sequence of gravel and discordant red sand overburden, but the contact between gravel and underlying bedrock, presumably shale, is not exposed. In the top of the gravel bed, directly underneath the red sand, a ferricrete horizon is present. The abrupt discordant boundary between the sand and gravel most probably represents a denudation hiatus and the ferricrete horizon, part of a former soil horizon, has been truncated and buried by deposition of the colluvial red sand and is now fossil.

THE SANDFONTEIN SAND DEPOSITS

Lower down on the pediment over 6 m of sand is exposed in excavations. No gravel layer is present in the profile and as yet it is not clear whether the gravel from the upper part of the pediment extends underneath the sand to this point.

A section through the sand deposit reveals three major zones, an upper, red (5YR 5/8) sandy loam (81% sand, 5% silt, 14% clay), about 2,5 m thick, followed by a yellow (5Y 7/3) loamy sand (87% sand, 4% silt, 9% clay), about 2 m thick, and finally a grey (2,5Y 7/2) sandy loam (82% sand, 4% silt, 14% clay), 1,5 m thickness being exposed. The differences in colour are most probably due to differences in groundwater conditions.

The most striking characteristic of the yellow-stained layer is the presence of a high concentration of iron concretions (see Fig. 3). In the author's opinion this zone of iron accumulation is also fossil and the continuation of the ferricrete horizon exposed in the gravel layer at the upper section of the pediment

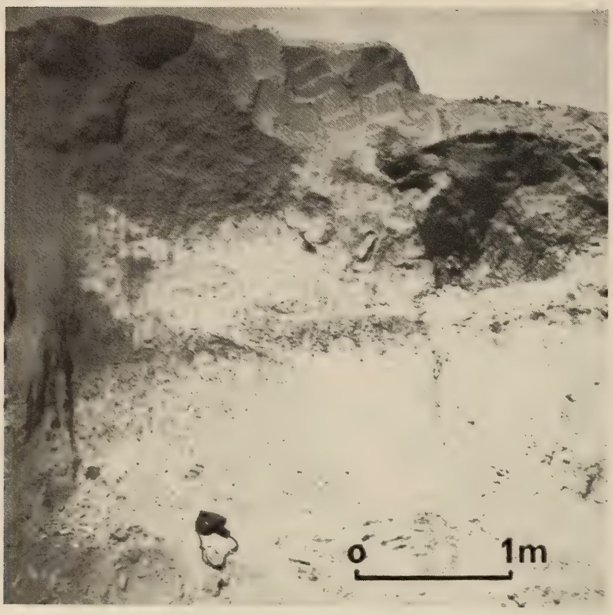

Fig. 3. Colluvial sand deposit showing the yellow-stained zone bearing iron concretions (dark specks), overlain by red sand.

described above. This would imply that there is a gradual facies change from gravel to sand in the downslope direction across the pediment. However, further investigations would be necessary to determine the precise relationship between the gravelly and sandy colluvial deposits at various points on the pediment slope.

The upper, red zone of this sand deposit appears to correlate with the red sand overlying the gravel bed at the upper end of the pediment. Support of this inference is furnished by evidence of fluviatile sorting across the pediment as shown by textural analysis of the red sand forming the smooth surface of the pediment. Samples taken at intervals, and at the same depth of 10 cm, show a downslope increase of the clay fraction from 8 per cent to 26 per cent and a corresponding decline of the sand fraction from 87 per cent to 66 per cent.

DISCUSSION

Concerning the gravel deposit described above, Linton (1969: 85) quotes a comparable instance from the northern slopes of the Magaliesberg, west of Hartbeespoort dam, and attributes its origin to gelifluxion sludge, 'of the type termed "head" or "rubble drift" in England'. According to Linton this and other similar surficial deposits in South Africa should be considered distinctive cold-climate forms and would serve 'to indicate the reality of Pleistocene cryonival and geliflual activity in South Africa'.

The present author cannot subscribe to the view of a distinct periglacial origin for the deposits concerned, first of all, as cryergic activity of such magnitude would only be generated at temperatures fluctuating around 0°C, such a drastic depression of temperature during the Pleistocene can hardly be assumed for the Pretoria area, the present annual mean temperature being 17°C. Secondly, the considerable proportion of fines contained in the matrix of the gravel, and especially the vast sand deposits on the pediment, the lower beds probably representing the downslope facies of the gravel deposit, attest to a comminution of quartzite bedrock, from which they have been derived, that could not have been accomplished by mechanical frost-shattering, but rather by deep chemical weathering under more humid conditions than prevailing at the present time. The iron-staining and impregnation giving the sediments their typical dark red colour, also indicate that the material has been released by intense chemical weathering. The well-developed joint system of the quartzite bedrock would permit of deep penetration of moisture, and hence weathering, producing not only fines but also coarse subangular fragments as seen in the gravel deposit

CONCLUSIONS

The major discontinuity in the colluvial deposits is that between the gravel bed and the overlying red sand (Colluvia II and I in Fig. 1). The nature of the deposits appears to indicate that the material originated from chemical weathering of the quartzite hillslope and was translocated by running water (sheet and rill wash). The two deposits represent climatological episodes during which more humid conditions obtained than at present, the older of the two, the gravel deposit, being attributable to fluviatile action and weathering of a greater intensity than the upper, red sand beds. Presumably, therefore, the gravel colluvium may be ascribed most reasonably to the last Pleistocene pluvial period, whereas the red sand beds may date from an Holocene pluvial episode of lesser intensity. The temperature depressions during pluvial periods would certainly not have inhibited chemical weathering, but rather, the increased availability of moisture, as a result of higher rainfall, higher frequency of winter snowfall, and lower rate of evaporation, must have more than offset the retarding effect of the lowering of temperature by, say, 5°.

It is also suggested by the present author that the sequence of two colluvia described above corresponds to the generalized section of typical superficial deposits as inferred by Cooke (1941: 26) for areas underlain by Karoo beds, the gravel layer being the equivalent of Cooke's pebble band, and the discontinuity between the gravel and the red sand overburden representing a former land surface on which the soil horizon with ferricrete had developed. Cooke terms this discontinuity the 'Middle Stone Age horizon', since artefacts of that age occur at this level. In the Pretoria area Middle Stone Age and older artefacts occur throughout the two colluvial layers.

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PAST CLIMATE DERIVED FROM CALCRETE AND N-VALUE

By

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(With 2 figures and 2 tables)

ABSTRACT

Since many pedogenic processes are climate-sensitive, it should be possible to use certain older pedogenic materials as indicators of the palaeoclimate. This statement is discussed on the basis of outcrops of hardpan calcrete in the northern and central Transvaal where the present climatic conditions do not appear to favour the development of this type of calcrete. It is attempted to show that the interaction of certain climatic factors as expressed by the N-value may provide a means of understanding the palaeoclimatic conditions during the later Cenozoic. It is shown in particular that changes of individual climatic factors need not be very great to cause such a change in the overall conditions that the formation of pedogenic materials may be initiated or terminated.

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INTRODUCTION

Although the road-building properties of weathered dolerite and other basic crystalling rocks as revealed by research do not appear to tie up with our present knowledge of the later Cenozoic of southern Africa, this research has been responsible for a closer look being taken as to how the present climate influences the weathering of these rocks.

That there is a relationship between the geological process of weathering, the performance of weathered natural construction materials and the present climate has always been assumed and as a result of the research mentioned a better understanding has been obtained of the interaction of these processes.

Indeed, this research has provided the means from which the engineering performance of weathered rocks can be predicted from a mathematical expression which defines the climatic equilibrium within which the rocks have been weathering.

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This expression is

$$N = \frac{12E_J}{P_a}$$

where N is a numerical value

E_J is the computed evaporation during January, the warmest month, and

P_a is the annual precipitation

The significant values of N are the integers 1, 2, 5 and 10 (Fig. 1), of which $N = 5$ is the most important. The precise meaning of these integers as well as the deduction of the expression (Weinert 1965, 1974) and the actual method of calculation (Weinert 1974) have been described elsewhere.

CALCRETE AND CLIMATE

Certain pedogenic materials, particularly calcrete and ferricrete, are sensitive to climate, a fact which has often been used to explain their distribution. Very frequently, probably because of the numerous stations in the world where rainfall is recorded and which allow the compilation of relatively reliable rainfall maps, the total annual rainfall has been the considered indicator. Rainfall is, however, only one climatic factor and its influence on soils and rocks does not depend only on the absolute quantity of rainwater that has fallen whether monthly or annually, but rather on the time available to the rainwater to act on soils and rocks before it is lost by run-off and evaporation.

In his work on calcrete, Netterberg (1969*a*, 1971) also considered that there is a connection between rainfall and the formation and distribution of these pedogenic materials. He suggested 550 mm and 800 mm of annual precipitation as critical quantities: in areas receiving less than 550 mm rain per year hardpan calcrete is common; where the rainfall is between 550 mm and 800 mm nodular calcrete can still be found and where the rainfall is more than 800 mm no calcrete occurs. This applies to most parts of southern Africa although occasional deviations from these observations do of course occur.

Apart from this relationship to rainfall, Netterberg also observed that there is a close relationship between the occurrence of certain types of calcrete and the N-value in which the integers mentioned previously play a particular role:

(i) where N is greater than 5 hardpan calcrete most commonly occurs,
(ii) where N is between 2 and 5 nodular calcrete is the most advanced stage of development,
(iii) where N is less than 2 no calcrete is found.

It may be added that ferricrete occurs predominantly where N is less than 5 and that the areas of use of both pedogenic materials in road construction are separated remarkably well by the contour of $N = 5$ (Fig. 2).

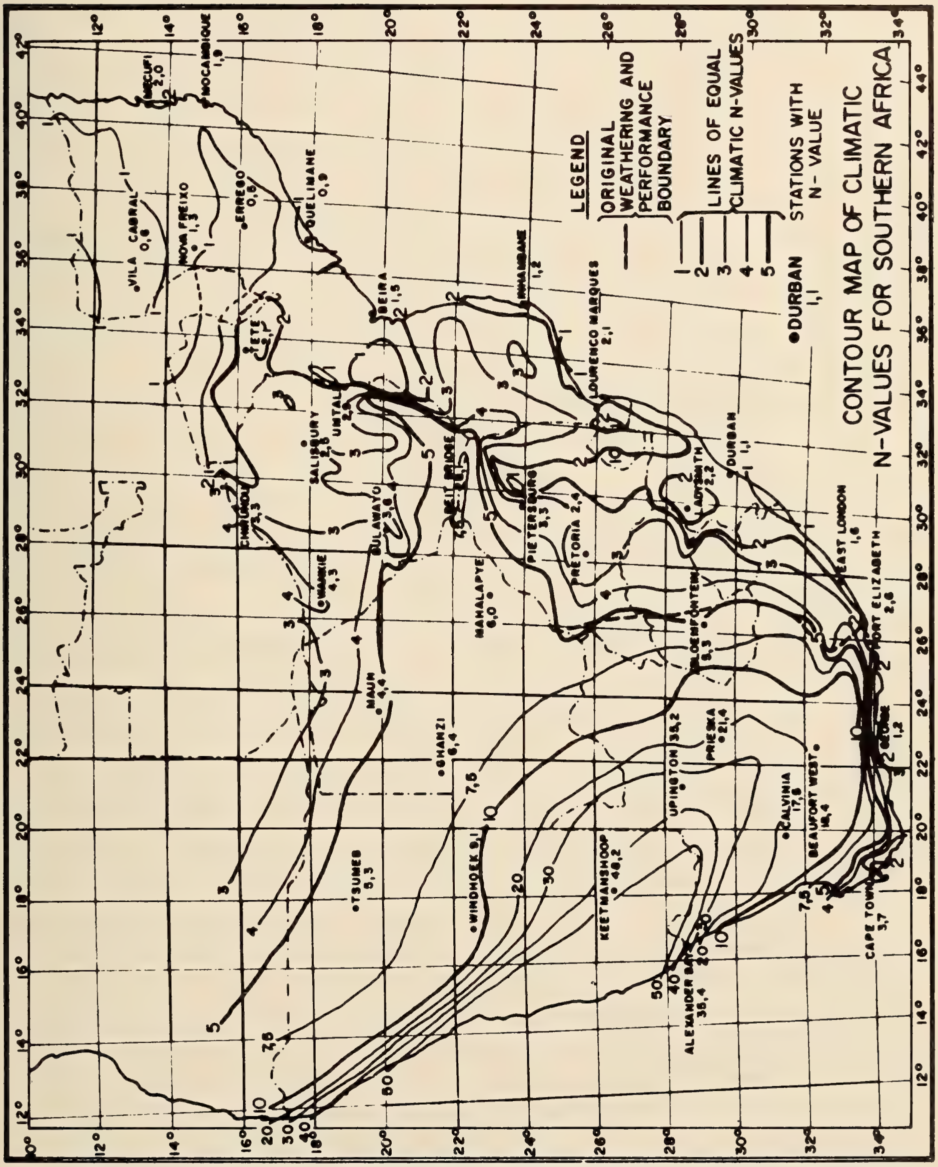

Fig. 1. Contour map of climatic N-values for southern Africa.

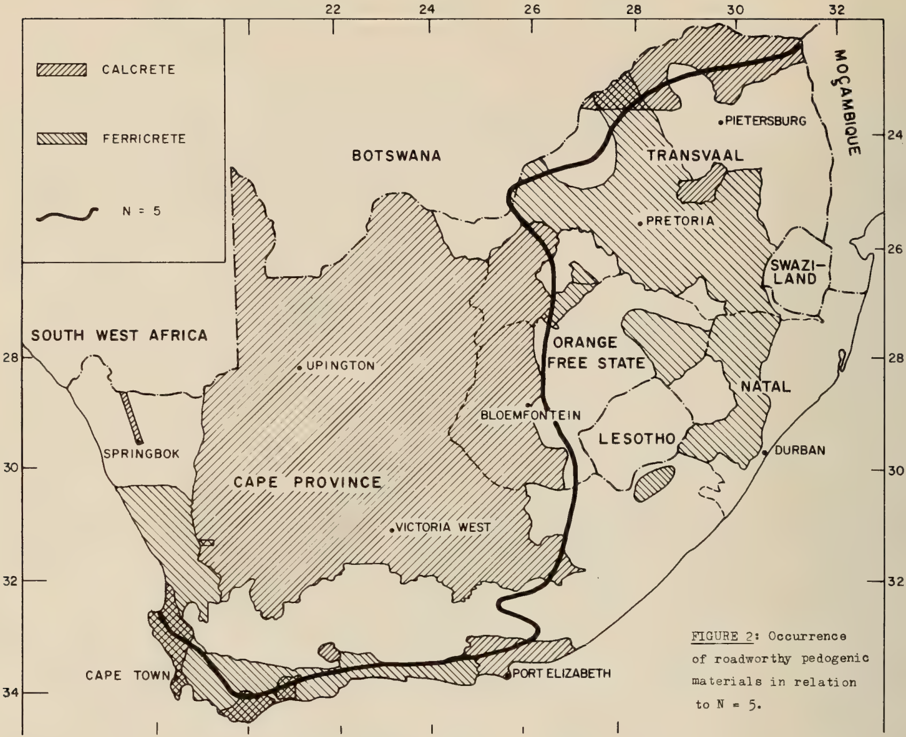

Fig. 2. Occurrence of roadworthy pedogenic materials in relation to N = 5.

There are of course also exceptions to the latter observation, e.g. the isolated occurrence of hardpan calcrete in the Springbok Flats of the central Transvaal, where the present climatic environment has an N-value of less than 5. An exception such as this may, however, be of particular interest, as it may be indicative of the climatic conditions that prevailed in the area during some part of the later Cenozoic and may provide the information necessary for estimating palaeoclimatic conditions of certain localities.

The isolated occurrence of large quantities of hardpan calcrete in the Springbok Flats appears to be an outlier of the tongue of hardpan calcrete which stretches south of the Soutpansberg towards Pietersburg. The southern boundary of this hardpan calcrete is about 15 to 20 km north of Pietersburg while in the vicinity of Pietersburg and south to about Potgietersrus only scattered calcrete nodules occur. There is a narrow zone of hardpan calcrete near Potgietersrus, particularly on outcrops of the Transvaal dolomite. That there has ever been a connection between the hardpan calcrete north of Pietersburg and that in the Springbok Flats can only be assumed but not be proved at this stage.

If, however, we consider present-day climate in connection with these calcrete occurrences, two apparent inconsistencies emerge.

1. *Annual rainfall.* Pietersburg receives 521 mm rain annually which is less than the limit suggested by Netterberg (1969*a*, 1971). The southern boundary of the hardpan calcrete, north of Pietersburg, is not reached until the annual rainfall has dropped far below 500 mm. On the other hand, most of those parts of the Springbok Flats where hardpan calcrete occurs, as well as most of such occurrences near Potgietersrus, receive more than 550 mm and even more than 600 mm rain per year. The only station in the Springbok Flats area with a reasonably comprehensive weather record since 1920 is Kopje Alleen (latitude 24.51S, longitude 28.41E), which has an annual mean rainfall of 621 mm.

2. *N-value.* The N-value of Pietersburg is 3,3 and, if N = 5 is considered as the limit of the occurrence of hardpan calcrete, the absence of this most developed type of calcrete at Pietersburg appears to be in line with this observation. In contrast, the N-value of the country between Pietersburg and the Soutpansberg, where there is much outcropping hardpan calcrete, is also generally less than 5 although the presence of smaller isolated areas where N is more than 5 cannot be entirely excluded. The N-values of the Springbok Flats are less than 5, that of Kopje Alleen being 3,9, and yet much hardpan calcrete is present.

'FOSSIL' CALCRETE AND PAST CLIMATE

Netterberg's (1969*a*, *b*, *c*) work has revealed that the hardpan calcretes north of Pietersburg as well as those in the Springbok Flats are 'fossil', which means that they are remnants of past conditions which were more favourable for their formation than those of today. It is obvious that calcrete, once it has been formed, can be preserved in a climatic environment not favourable to its formation. Both the stage of development attained by the calcrete and the degree of difference between the original and any later climatic conditions will affect the duration of this 'survival'.

A hardpan calcrete is the most advanced stage of calcrete development and it will be preserved longer and under more severe long-term changes of climate than any other stage. 'Fossil' calcrete may therefore be taken as an indicator of climatic conditions of the past and this will be particularly the case if the hardpan stage had been reached.

The occurrences of hardpan calcrete north of Pietersburg and in the Springbok Flats will now be considered in the light of climatic changes, and in the discussion which follows it will be assumed that the presence of the most advanced stage of calcrete development really is an indicator of the climate that prevailed during the period of its formation, i.e. a N-value of 5 and more or a mean annual rainfall of less than 550 mm.

Rainfall

It has been said that the country between Pietersburg and the Soutpansberg, in fact the whole area between the Strydpoortberge and the Soutpansberg, receives less than 550 mm rain per year. This means that, if rainfall were the sole climatic factor which favours or disfavours the formation of hardpan calcrete, this material should be present in the whole area. The present climate or rather the present rainfall would then be that which also caused the occurrence of the hardpan calcrete whose southern boundary is now about 15 to 20 km north of Pietersburg and which coincides better with the 450 mm isohyet of the present annual rainfall. It should be noticed that the other pedogenic factors, parent material, topography, biology and time are not considered in this paper.

The annual rainfall in most of the Springbok Flats where hardpan calcrete occurs is now more than 550 mm, and in parts it is even more than 600 mm; for instance, the annual rainfall at Kopje Alleen is 621 mm. The annual averages in this area may vary from decade to decade by more than 100 mm. The calcrete in this area appears to be 'fossil' and a long lasting decrease in the annual rainfall of the order of 70 to more than 100 mm, i.e. toward the lower end of the present 'normal' variation, would be required if the formation of hardpan calcrete were governed by rainfall alone. This would be a considerable decrease which would also have a noticeable effect on other climatic factors. Presuming such a decrease the rainfall in the Springbok Flats would then be of the same order as it is now about one degree further north, and the general climatic conditions would be rather different from those pertaining at present in the country between the Strydpoortberge and the Soutpansberg.

N-value

All the areas in the northern and central Transvaal which have been discussed possess outcrops of hardpan calcrete and in all of them the N-value is obviously less than 5. Most hardpan calcrete in southern Africa, however, occurs where N is more than 5 (Netterberg 1969*a*, 1971).

The following climatic data are required for the determination of the N-value:

(1) the mean annual rainfall;
(2) the average air temperature of the warmest month in southern Africa; this is usually January;
(3) the average relative humidity of the warmest month; and
(4) the mean wind speed of the warmest month.

Applying Olivier's (1964) expression for daily evaporation and a wind correction, the N-value is calculated from:

$$N = \frac{372 \ c_J(0,58 + 0,14 \ V_J)}{P_a \ w\varphi S}$$

where c_J is the wet bulb depression in °C for January;
V_J is the mean wind speed of January in m/s;
P_a is the mean annual rainfall in mm, and
$w\varphi S$ is the correction for the monthly field-water requirements depending on latitude (Olivier 1964)—this is 0,78 for the latitude of Pietersburg and 0,79 for that of the Springbok Flats.

It has already been said that the N-value of Pietersburg is 3,3 and that of the Springbok Flats is between 3 and 4, that of Kopje Alleen being 3,9. Any individual climatic factor would have to change considerably, leaving all others unaffected, for the N-value to change to 5; for instance, if the N-value of the two stations were to increase to 5, e.g. the annual rainfall at Kopje Alleen would have to drop from 621 mm to about 480 mm, and the relative humidity at Pietersburg, where the relative humidity during January is remarkably high, would have to decrease from the present 69 per cent to 52 per cent.

In any climate, the change of any one factor is influenced by the overall situation and may affect all the other climatic factors. A decrease in the rainfall will thus mostly be associated with a decrease in the relative humidity, possibly an increase in the air temperature and perhaps also in the average wind speed. Considering therefore the climatic changes required to increase the N-value at Pietersburg and in the Springbok Flats to 5, an entirely different picture emerges from that in which rainfall alone was being considered as the only cause of the formation of hardpan calcrete.

The average relative humidity during January at Pietersburg is 69 per cent nowadays and it would have to decrease to about 60 per cent to agree with the present conditions north and south of the town. Such a decrease would most likely be associated with a slight rise in the average January temperature and the wind speed, and a minimal decrease in the total annual rainfall might also occur.

The following situation would then be one of many which would change the N-value of Pietersburg from the present 3,3 to 5:

Table 1 Possible change in conditions required at Pietersburg to bring N-value to 5

Climatic factors	*Present condition*	*New condition*
Mean annual rainfall	521 mm	500 mm
Mean temperature in January	21,5°C	23°C
Mean relatieve humidity in January	69%	60%
Mean wind speed of January	2,6 m/s	2,9 m/s
N-value	3,3	5

At most localities of the Springbok Flats, the major change would have to occur in the annual rainfall which is now 621 mm at Kopje Alleen. A comparison of the relevant relations at all major weather stations of the Republic reveals that, when the annual rainfall is of the order of 500 to 600 mm, a decrease of 4 to 5 per cent in the relative humidity of the warmest and most rainy month would be a reasonable estimate if the total annual precipitation decreased by 50 mm. If the average wind speed of the warmest month remains unchanged, the average temperature of the warmest month might rise by one degree Celsius.

To bring the N-value of Kopje Alleen to 5 the following changes in the climatic conditions represent one of many possibilities:

Table 2

Possible change in conditions required at Kopje Alleen to bring N-value to 5

Climatic factors	*Present condition*	*New condition*
Mean annual rainfall	621 mm	570 mm
Mean temperature in January	23,5°C	24,5°C
Mean relative humidity in January	62%	58%
Mean wind speed of January	3,1 m/s	3,1 m/s
N-value	3,9	5

CONCLUSIONS

The above two tables show that no radical changes in the present climatic conditions would be required if the value of $N = 5$ were considered a requirement of the development of hardpan calcrete in the Pietersburg, the Springbok Flats and possibly all other relevant areas. It is very unlikely that a natural event, such as the pedogenic process of calcrete formation, depends only on one single climatic factor. With numerous interacting climatic factors, however, each individual factor need not change much to bring about such an alteration in the general conditions that calcrete development may begin or be brought to an end. A mathematical expression which is a ratio of the interaction of various climatic parameters offers a means of estimating such past conditions, particularly if the former climate can be connected to the formation of datable, climatic-sensitive materials such as calcrete. The N-value has been used to demonstrate this and it shows that all required variations are small and well within those fluctuations which 'normally' occur today. This may indicate even that no radical changes of climate may have occurred in the areas concerned at least during the later Pleistocene.

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SECTION 3

PALAEOECOLOGY

LATE QUATERNARY ENVIRONMENTAL CHANGES IN SOUTHERN AFRICA

By

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(With 5 figures)

ABSTRACT

The climatic regime of southern Africa is strongly influenced by the evolution of the Antarctic ice sheet which dominates the atmospheric and oceanic circulation. This climatic system is of mid-Tertiary age. During the Quaternary glaciations world-wide lowerings in temperature caused northward shifts of the climatic belts in the southern hemisphere. As a consequence of these shifts southern Africa was much more exposed to the zone of the Westerlies with their strong winds, the invasion of many depressions, regular influxes of cold polar air and much more rain than at present.

The drastic changes which occurred in the major ecological regions during the last glacial cycle are described in broad outline. From archaeological and radiometric datings the inference can be made that during full-glacial and interglacial periods climatic conditions in several regions were so adverse to human life that long time gaps exist in the occupation of prehistoric sites in these regions.

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INTRODUCTION

The present general systems of atmospheric and oceanic circulation of the southern hemisphere are of mid-Tertiary age. These systems could develop only after the greater part of Antarctica was ice-covered and the South Polar heat sink had originated. The production of cold Antarctic Bottom Water (Shackleton & Kennett 1975) and the formation of the Circum-Antarctic Current (Kennett *et al.* 1974) in Oligocene times caused the present general distribution of the different water masses in the Antarctic Ocean.

The atmospheric circulation was strongly affected by the great difference in temperature which had developed between Antarctica and the tropics and which had steepened the pressure gradient between these regions. The result of this development was a strong zonal circulation in the upper troposphere which had again a great influence on the position of the high and low pressure

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cells of our surface climate and therefore on the steering of the atmospheric and oceanic circulations.

The present climatic system of southern Africa is dominated by the following three climatic zones:

1. The Inter-Tropical Convergence Zone (I.T.C.Z.) which moves northward and southward with the sun. This tropical system brings precipitation to meridional zones of Africa about as far south as the parallel of 20°. Further southward the interference of the next system disturbs the regular rainfall distribution because of a strong aridifying influence coming from the west.
2. The subtropical zone, which in the region of southern Africa consists of three anticyclones, one over the oceans on either side of the subcontinent and one which persists over the plateau of the interior at 2 000 m altitude (Jackson 1952; Trewartha 1966). The drying influence of these anticyclones, which are subject to small seasonal meridional displacements round 30°S. latitude, is at present the most important component of the climate of southern Africa. The more stable South Atlantic high pressure system has the greatest influence on this climate as it is situated much nearer to the coast than its Indian Ocean counterpart. This extremely aridifying influence along the west coast which reaches far inland is aggravated by the Benguela Current and its associated cold upwellings, which are responsible for the existence of the hyper-arid Namib Desert. The anticyclone over the Indian Ocean is situated further away from the continent and humid maritime and tropical air can as a consequence often enter the eastern half of southern Africa.
3. The zone of mid-latitude westerlies moves slightly northward in winter and then brings cyclonic rain to the south-western Cape coastal area.

This climatic system is ancient, but the topographical distribution of its ocean and wind currents changed significantly in the course of time. The very short description given above applies to the conditions prevailing during the second half of the interglacial in which we are living at present. Variations of considerable magnitude have occurred during the Quaternary glacial and interglacial maxima and during stadials and interstadials which were of different intensity and duration.

THE GLACIAL CLIMATE

During the last glacial important changes took place in the oceans surrounding southern Africa. Oceanographic research by Hays *et al.* (1976) has shown that during the coldest maximum of this glaciation of Würm-Wisconsin age, 18 000 years B.P., the Antarctic Polar Front was displaced considerably northward, especially in the Atlantic and Indian Ocean sectors but only slightly south of South Africa. The cold Antarctic Upper Water penetrated from 6 to 10° latitude northward and pack ice covered the Antarctic Ocean even in summer as far north as 55°S. The cooling effect of these changes greatly steepened the atmospheric pressure gradient and as a consequence strongly activated the atmospheric and oceanic circulations. Cold air and water masses could penetrate much further northward and must have had a profound influence on the mid-latitudes and the subtropical regions of the southern hemisphere. The general world-wide lowering in temperature during the glacial maximum will consequently have been greater in those parts which were exposed to these polar influences. A typical example of this is the sub-antarctic island Marion which was glaciated during the last glacial period (Van Zinderen Bakker Sr 1969).

The northward displacement of cold water along the west coast of southern Africa during the last glaciation has been studied by Bornhold (1973). The results of his investigations of marine sediments off the coast of Angola can only be explained by the assumption that a northward shift of the Atlantic Ocean anticyclone forced the Benguela Current with its high productivity water along the well-aligned coast north of Mossamedes. The drying influence of this system must have affected western Angola, Zaïre and Congo as has been anticipated by the author (Van Zinderen Bakker Sr 1967).

It is possible that cold water also penetrated further north along the south-east coast of South Africa so that the warm Agulhas Current could not reach the south coast of the continent as is the case at present. Vincent (1972) has shown that the temperature of the surface water in the southern end of the Moçambique Channel before 10 000 years B.P. was 5°C colder than at present.

The consequences of these considerable changes in the atmospheric and oceanic circulation, which aggravated the general lowering in temperature, were dramatic for the palaeoenvironment of southern Africa. The northward movement of the climatic zones extended the influence of the westerlies with their accompanying winter rainfall, low temperatures and great windforce. The cold fronts, which caused regular influxes of very cold polar air deep into southern Africa, could, by comparison with present conditions at higher latitudes, have penetrated the continent a hundred times a year. It is therefore possible that in exposed areas temperature drops of 10°C occurred regularly, especially in winter. Cryoclastic phenomena as described by Butzer (1973), 'periglacial' features as studied by a number of authors (Alexandre 1962; Sparrow 1967, 1974; Harper 1969; Hastenrath 1972) and the production of roof spall in caves of the Cape coastal region (Butzer 1973) could well be explained by recurrent drastic lowering in temperature in winter. Decreases in temperatures of 8 to 10°C have been suggested by Harper (1969) for the high mountains of Lesotho, by Butzer, (1973) for the phenomena at the southern coast and by Talma *et al.* (1974) even for the central Transvaal. More palaeotemperature determinations will, however, be necessary to come to an accurate assessment of the average temperature during the last glacial maximum.

The cyclonic winter rain may not have penetrated southern Africa as far as the influxes of polar air. Indications for the northern limit of these cyclonic rains can perhaps be obtained from biogeographic evidence in the southern

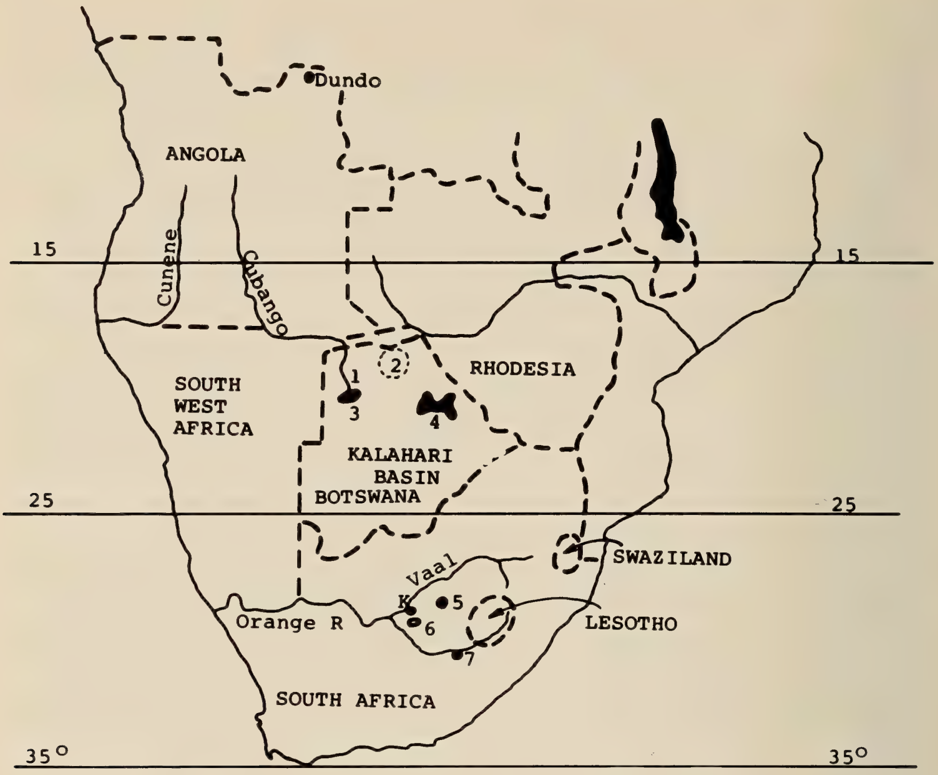

Fig. 1. Locality map of the interior plateau and the Kalahari region.
1 = Okavango delta; 2 = Mababe depression; 3 = Lake Ngami; 4 = Makarikari; 5 = Florisbad; 6 = Alexandersfonteinspan; 7 = Aliwal North; K = Kimberley.

Namib (Haacke in Van Zinderen Bakker Sr 1975) from the high lake levels of Alexandersfonteinpan (Butzer, Fock *et al.* 1973), the pollen analytical results of Aliwal North (Coetzee 1967) and Florisbad (Van Zinderen Bakker Sr 1957) and the sequence of the Riverton Formation of the Vaal Basin (Butzer, Helgren *et al.* 1973). It is well possible that the cyclonic trajectories were displaced northward in winter by at least 10° latitude, so that they could in certain localities reach the 24th parallel of latitude. During interglacial maxima the reverse development will have taken place and tropical rain could freely penetrate the Transvaal while the Orange Free State and the Cape Province would generally have had a fairly dry to very dry climate as the winter rain did not touch the south-western Cape area regularly.

ENVIRONMENTAL CHANGES

The impact of the drastic climatic changes on the vegetation will be treated in more detail elsewhere (Van Zinderen Bakker Sr 1976). On purely theoretical grounds certain vegetation reconstructions can be implied, but is not yet possible to draw any maps of former vegetation patterns as pollen analytical records are so far only available for the Cape coastal region and the inland plateau. These reconstructions can therefore be attempted only in very broad outline and will apply primarily to the rather extreme conditions of the warmest and coldest periods. It should, however, be realized that during the long duration of the Quaternary an endless variation of ecological conditions occurred. These various stages, which could have been of long duration, all form part of the full glacial-interglacial cycle. For some regions the important stages will be described using the terminology proposed by Von Post (1946), Firbas (1949: 110) and Iversen (1954, 1958) in which the stage of the maximum cold is called the cryocratic stage. The protocratic stage with rising, though oscillating, temperature leads to the mesocratic ecological stage, during which the temperature reaches optimum conditions. The cycle is closed by the telocratic stage during which temperature is declining.

The austro-afro alpine region

The 'periglacial' phenomena described from the higher altitudes of the eastern escarpment suggest that during the last glacial maximum, depending on the accepted temperature gradient, a drop in temperature of 5,5 to 9,0°C could have occurred (Harper 1969). Under such conditions the upper limit of the vegetation will have been lowered by some 1 000 m. This drastic change will have driven all the trees and ravine forests away from altitudes above 1 100 to 1 200 m and will have robbed the upper reaches above about 2 000 m of all their vegetation. Radiocarbon dates of the age of the swamps, which occur at about 3 000 m altitude in Lesotho, show that vegetation only settled here again after the beginning of Hypsithermal warming of the climate (Van Zinderen Bakker Sr & Werger 1974). It would certainly have been impossible for Middle Stone Age and Later Stone Age people to live permanently in the mountains at higher altitudes during full-glacial or late-glacial times. Willcox (1974) offers this possibility as one of his explanations for the lack of prehistoric settlements of such age at higher altitudes.

The plateau of the Orange Free State (Fig. 2)

The present-day grassveld plateau of the Orange Free State and adjacent areas has been subjected to radical ecological changes. During full-glacial times the alpine grassland, which at present covers the eastern escarpment above the tree limit, will have invaded this plateau under severely cold and rainy conditions. Climatic amelioration will have led to the protocratic conditions of the second half of our present interglacial which are characterized by sweet grassveld (*Cymbopogon–Themeda*) with summer rain and limited night frost in winter. The warmest mesocratic period of the interglacial must, according to pollen analytical results, have seen the invasion of the semi-arid Karoo (Van Zinderen Bakker Sr 1957; Coetzee 1967) (Fig. 3). According to

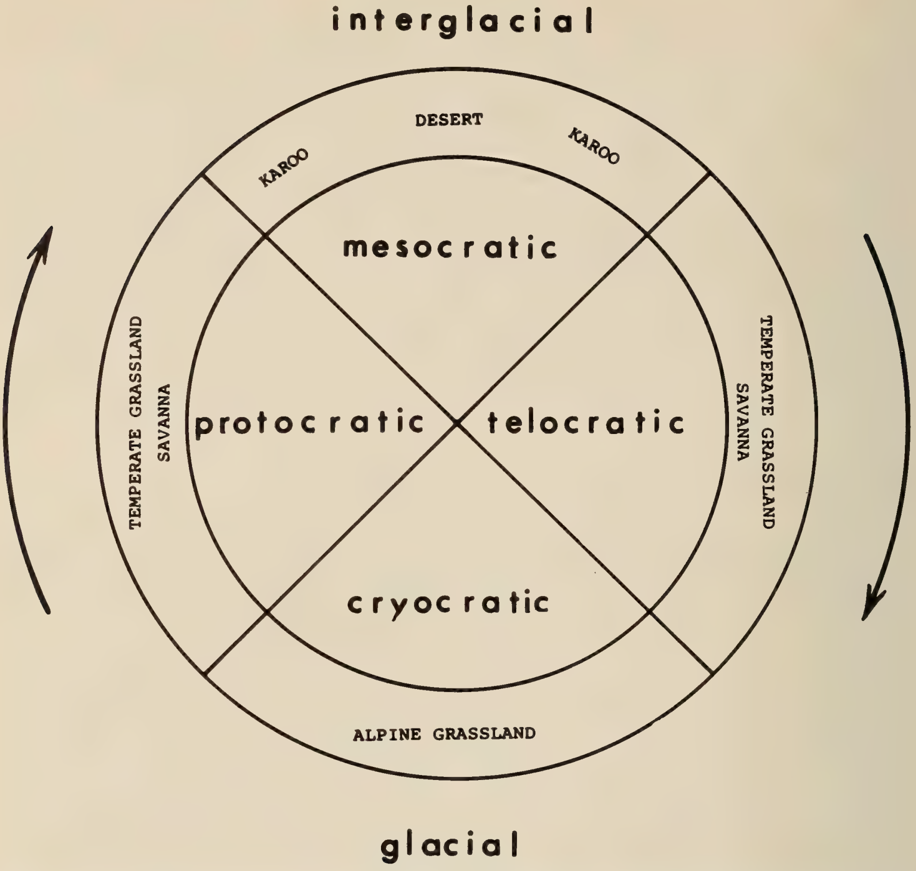

Fig. 2. The vegetation types of the full glacial-interglacial cycle of the Highveld and Cape Plateau.

geomorphological information (Butzer, Helgren *et al.* 1973) even drier conditions in the western part promoted the spread of windblown sanddunes.

The valuable study by J. Deacon (1974) indicates that this inland plateau was inhospitable to prehistoric hunter-gatherers between 9 500 and 4 600 years B.P. During this period no occupation sites are known on this plateau, which was then covered by a very arid vegetation.

The Cape coastal region

This coastal region received the full impact of the strong winds; the influxes of polar air and heavy rainfall were not limited to winter only. The cryoclastic evidence and the fossil assemblages found in the caves suggest that during full glacial times the coastal plain was mainly covered by grassland (Butzer & Helgren 1972; Klein 1974).

Site	C^{14}-age Years B.P.	Stratigraphy	Vegetation	Archaeology	Climate	European Chronostratigraphy (B.P.)	
INTERIOR PLATEAU (J.Deacon,1974)	4600 ↕ 9500		probably dry Karoo	no occupation sites	probably very dry warm	HOLOCENE	4400 Atlanticum 7200 Boreal 8600
ALIWAL NORTH (J.A. Coetzee, 1967)	9650	Zone Z	Karoid dry grassveld		very dry, warm	LATE GLACIAL	Preboreal 10100
		Zone Y	grassveld		wetter, cooler		Upper Dryas
	11250						10900
		Zone X	Karoo		dry, warm		Alleröd Int.
	11650						11850
		Zone W	grassveld		wet, cool		Older Dryas
	ca 12200						12100
		Zone V	Karoid		dry, warm		Bölling Int.
	ca 12600 ca 13185						12400
		Zone U	grassveld		wet, cool		Oldest Dryas
	12600						
FLORISBAD (v. Zinderen Bakker 1957)	19350	Peat III	alpine grassveld	M.S.A.	wet, cold	PLENIGLACIAL	Upper Pleniglacial
	ca 25000				wetter, cooler		
	28.450	Peat II	dry Karoo	M.S.A.	oscillations: wet - cold to dry - warm		29000 Denekamp Int.
	> 48900	Peat I Basal Peat	dry Karoo		wet oscillation very dry, warm		

Fig. 3. The interior plateau during the Late Quaternary. Chronostratigraphy and environmental changes.

These climatic conditions will have been most adverse to the life of prehistoric man. In this connection Klein (1974) gives an interesting summary of the hiatus in occupation which is known for the caves in the coastal region and further inland. This gap, which is in the order of tens of thousands of years, falls between the occupation by MSA and LSA people. It has been suggested that the very inhospitable climate during full-glacial times may have been one of the factors which had driven man away from those caves which were very exposed (Van Zinderen Bakker Sr 1976). Other factors, such as scarcity of food resources or the great distance from the sea, may well have contributed to the non-occupance of the caves during cryocratic times.

The different stages of the glacial-interglacial ecological cycle are not known for the Cape coastal region, but the pollen analytical results obtained by Schalke (1973) and Martin (1968) provide some valuable information which can be combined with palaeontological evidence (Klein 1974). The following general explanation has been offered (Van Zinderen Bakker Sr 1976) (Fig. 4). In the Cape coastal region temperature and humidity are negatively correlated as can be concluded from the winter-rainfall climatic pattern. Evergreen forest could spread widely only during protocratic and telocratic times when temperature and humidity reached medium values. These conditions prevailed at the

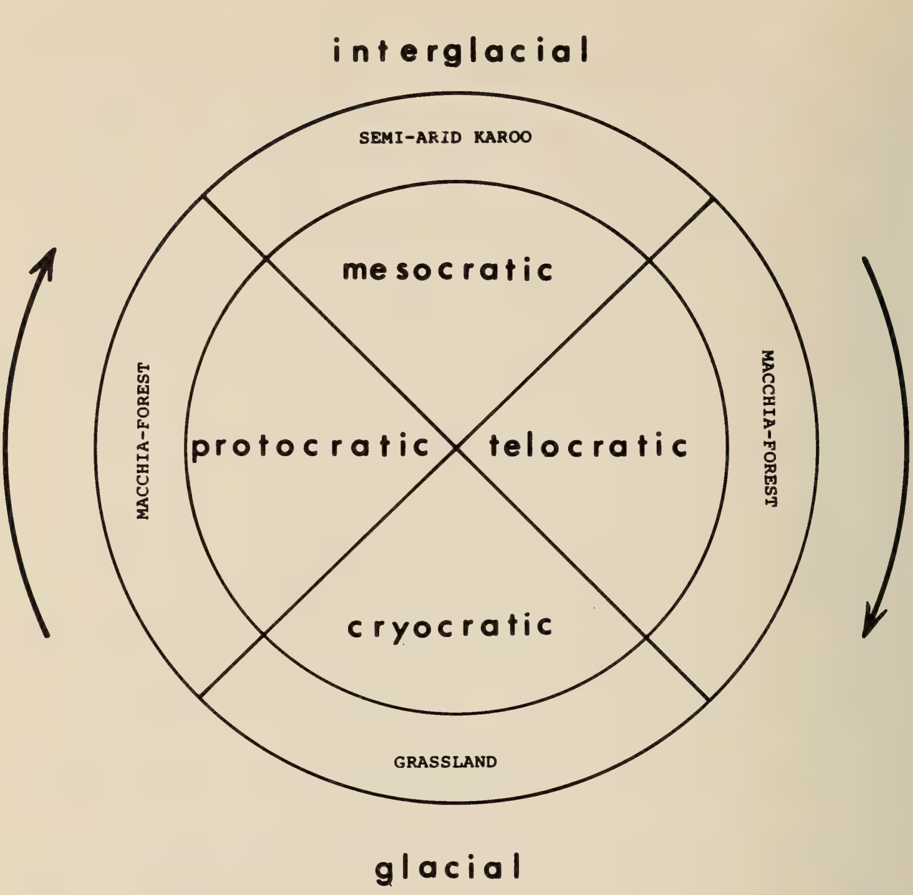

Fig. 4. The vegetation types of the full glacial-interglacial cycle of the southern Cape coastal region.

beginning and end of the Holocene thermal optimum. During the optimum the climate was too dry for the evergreen forest, and Karoo-like vegetation and dunes spread along the coastal plain. Macchia and *Podocarpus* forest, which are not so sensitive to frost, will have been dominant during protocratic and telocratic times respectively before conditions were favourable for the coastal evergreen forest. These considerable changes in climate and vegetation may not have been of the same nature in the entire extended coastal region. Much more research is needed, especially pollen analytical studies, to elucidate the complicated evolution of the environment in this region.

The west coast and the Kalahari Basin (Figs 1, 5)

As previously discussed, the aridifying influence of the South Atlantic anticyclone and the Benguela Current moved in a meridional direction northward during colder periods and poleward during warmer episodes. Hyper-

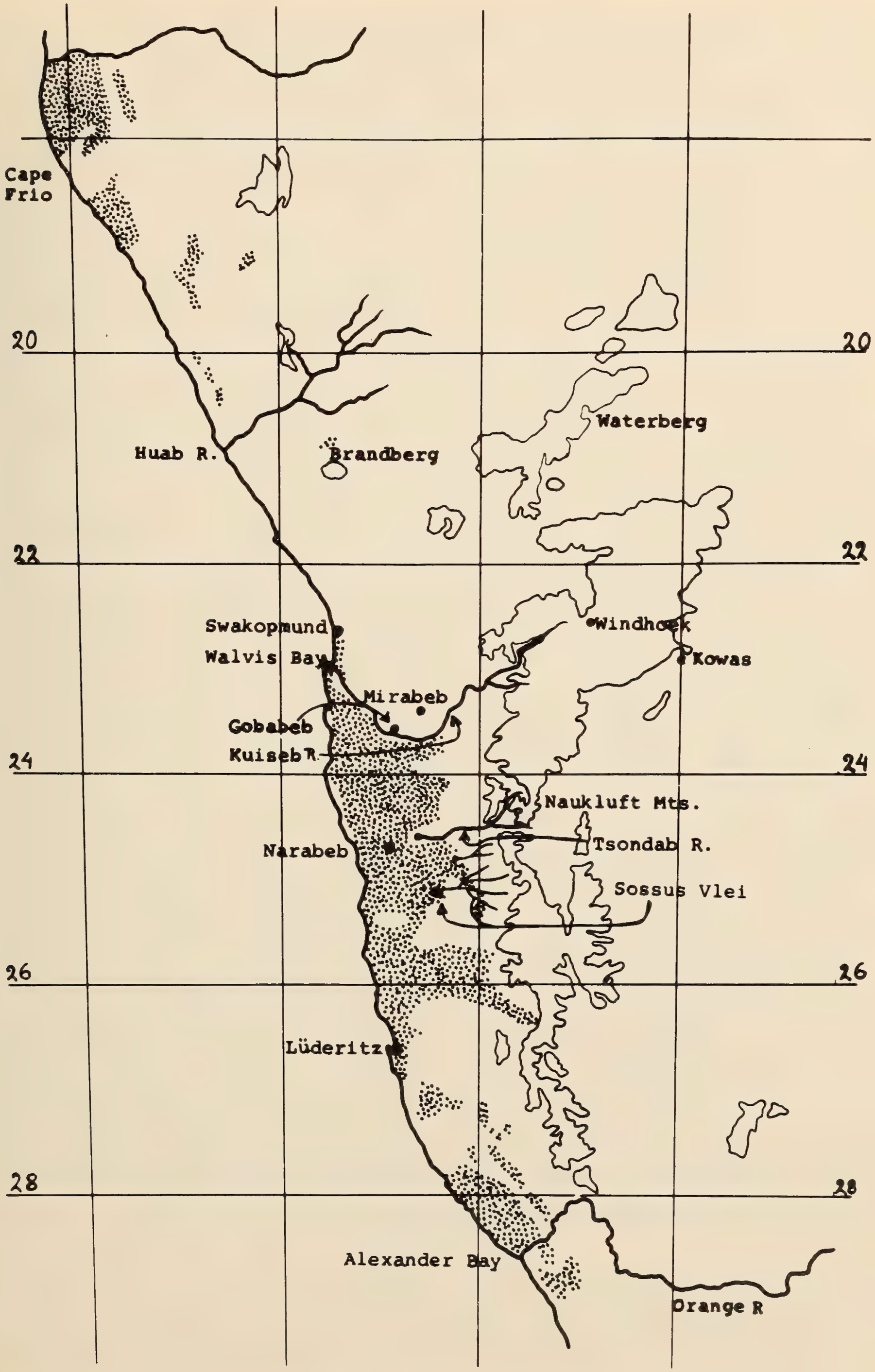

Fig. 5. Locality map of the Namib Desert.

desertic conditions existing in the coastal region and Kalahari sand movements are strongly correlated with this system (Van Zinderen Bakker Sr 1975). Some radiocarbon dates from northern Angola support the inference that the redeposited Kalahari Sand members were active during colder periods.

Too little information is at present available for the assessment of former changes in rainfall in this vast region. On theoretical grounds it can be assumed that at certain warmer stages tropical rainfall invaded the northern part, while winter rainfall may have penetrated the southern Namib and perhaps even Botswana during full-glacial periods. A study of the history of the large pans in Botswana, especially of those which are not connected with the Okavango–Botletle river system, could throw much light on former climatic conditions. Similar studies of the isolated pans which occur in the barchan dunes of the southern Namib are of great importance as is already shown by the description of the Tsondab vlei by Seeley & Sandelowsky (1974). The vlei deposits contain much Early Stone Age material and it appears as if the Tsondab River, which originates in the Naukluft Mountains to the east, was able to reach the ocean during a former period with higher rainfall. The Sossus vlei further south could also yield important palaeoclimatic information. The Mirabib Rock Shelter north of the Kuiseb River, which is being studied by Sandelowsky (1974), contains a wealth of information covering a period of nearly 10 000 years.

From a biological viewpoint it seems as if former higher rainfall in the southern Namib Desert could only have been of a southern origin and must consequently have been winter rain which penetrated far northward during full-glacial times. Summer rain of I.T.C. origin could only reach the southern Namib during abnormal mesocratic conditions when the South Atlantic anticyclone was situated extremely far south. A climatic assumption of the latter kind cannot offer a valid explanation as it would mean that the whole Namib received summer rainfall over its full length. Such 'pluvial' conditions are not congenial with the rich hyper-desertic adaptations which are found in the barchan biota. These speciations point to great antiquity and an undisturbed environment. It can therefore be accepted that a rainfall maximum of a northern origin can never have affected the core of the Namib Desert (Koch 1962).

An attempt will not be made to elaborate on the Late-Quaternary history of the vast woodland regions which cover extensive areas of southern and East Africa. Detailed information on this region is still lacking, although it is known that these woodlands received less rainfall during the last glacial (Hamilton 1972) and were favoured with higher humidity during warmer periods. It is also not possible to venture into the unknown climatic and vegetational history of the east coastal region of southern Africa.

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RECENT FAUNAL STUDIES AT MAKAPANSGAT LIMEWORKS, TRANSVAAL, SOUTH AFRICA

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(With 5 figures and 1 table)

ABSTRACT

A brief review is given of recent work done on the Makapansgat Limeworks Hyaenidae, machaerodont and feline sabre-tooth cats and the Hystricidae. The smallest *Hyaena* present is confirmed as *H. h. makapani. H. brevirostris* is noted as possibly occurring. *Crocuta* is recorded for the first time in this deposit. A form of sabre-tooth, recently wrongly described as *Megantereon problematicus*, is reassessed as *Homotherium* cf. *nestianus*. Details of several specimens of *Dinofelis* are given, including a complete skull of *D. barlowi* and of the large part of a semi-articulated skeleton belonging to another individual. Three species of hystricid rodent are present at Limeworks. The largest, *Xenohystrix crassidens* Greenwood, has atherurine features in its teeth. *Hystrix makapanensis* and representatives of the modern species *H. africaeaustralis* are very similar, except for size and minor differences in tooth morphology. Comments are made on the palaeoecology of the area based on the described groups and it is postulated that the immediate vicinity of the cavern supported subtropical riverine bush and forest up to the end of Lower Phase I times. From comparisons with radiometrically dated deposits in East Africa, it is suggested that the Phase II Breccia was laid down at the most 2,75 m.y. ago, which would make the vast majority of the deposit technically Pliocene.

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INTRODUCTION

This paper serves to summarize research on three groups of fossil mammals from the Makapansgat Limeworks which has been completed recently, or which is about to be completed. The animal groups concerned are the Hyaenidae (R.M.R.), the machaerodontine and feline sabre-tooths (G.E.C.) and the Hystricidae (J.M.M.). Collation and some interpretation, as was the original supervision of the projects, are by A.R.I.C. Full accounts of each aspect of this report will appear elsewhere.

Proc. sth. Afr. Soc. Quat. Res. 1975.
Ann. S. Afr. Mus. **71**, 1976: 153–165, 5 figs, 1 table.

MATERIAL STUDIED (Table 1)

HYAENIDAE

Hyaena hyaena makapani (Toerien) (Figs 1–2). This is the smallest hyaena occurring at the Limeworks and on the basis of statistical analyses of the molars and premolars is confirmed as being a subspecies of *H. hyaena*, as was originally suggested by Ewer (1967). A supposed ancestor of *H. h. makapani* from the Cape has recently been described by Hendey (1974). The horizon of his species (*H. abronia*) clearly antedates the Limeworks Grey Breccia.

The technique used here for comparing the dentitions of hyaenas is an analogue of that devised by Simpson *et al.* (1960: 357). This is a graphical method using percentages (Fig. 1), in preference to logarithmic scales, as it is more convenient to use.

An interesting discovery was a lower jaw and a maxilla with the deciduous dentitions *in situ*. From these specimens, the order of tooth eruption and replacement could be deduced (Fig. 2).

The adult formula of *H. h. makapani* is $\frac{3:1:4:1}{3:1:4:1} = 36$ while the juvenile formula is $\frac{3:1:3:0}{3:1:3:0} = 28$ (Figs. 2A–B). These discoveries are important in confirming Toerien's (1952) description of isolated deciduous upper cheek teeth, which were not accepted by Ewer (1967: 114) as being from *Hyaena*. The deciduous dentition of hyaenas is so unlike the permanent dentition that isolated deciduous teeth are more likely than not to be wrongly identified (Kitching pers. comm.). All age classes are represented, from the very young to the almost senile.

About 37 per cent of the *Hyaena h. makapani* material was estimated to be one year old or less at death, based on tooth wear and eruption features. This compares with 33 per cent for hyaenas observed by Kitching (1963: 40) at Pin Hole Cave in Derbyshire, England. The implication from this is that juvenile hyenas are at risk when their teeth are replacing and tend to die in their dens from malnutrition and/or infection. It is therefore possible that parts of the Limeworks cavern may have been used as a hyaena lair during Grey Breccia times.

Hyaena cf. *brevirostris*.. All the specimens assigned to this large taxon are very fragmentary, with heavily worn teeth and this identification is therefore uncertain. This size class of scavenger (if scavenger it was), with its characteristic tooth size and structure, is clearly adapted to feed on the remains of animals possessing thick-walled bones, and hence by implication of moderate to large size. Speculations on the imbalance of specimens when compared with the foregoing is not profitable, when so little is known of the conditions under which the deposit accumulated. However, in the lower levels of the Limeworks, i.e. Grey Breccia, there are two species of hyaena, one a small generalized type

Table 1. Distribution of material stratigraphically.

Taxa present Stratigraphy (after Brain 1958 fig. 93)	*Hyaena hyaena makapani*		*Hyaena* cf. *brevirostris*		*Crocuta* cf.* *crocuta*		*Homotherium* cf. *nestianus*		*Dinofelis barlowi*		*Dinofelis* sp.		*Xenohystrix crassidens*		*Hystrix makapenensis*		*Hystrix africaeaustralis*	
	No. of Speci-mens	Min. No. of indi-viduals	No. of Speci-mens	Min. No. of indi-viduals	No. of Speci-mens	Min. No. of indi-viduals	No. of Speci-mens	Min. No. of indi-viduals	No. of Speci-mens	Min. No. of indi-viduals	No. of Speci-mens	Min. No. of indi-viduals	No. of Speci-mens	Min. No. of indi-viduals	No. of Speci-mens	Min. No. of indi-viduals	No. of Speci-mens	Min. No of indi-viduals
Phase II					1	1											2	2
Upper Phase I Pink, or Cercopithecoid Breccia											1	1	1	1	2	2	1	1
Lower Phase I Grey Breccia	218	26	5	2			2	1	3	1	2	1	40	13	8	4	17	6
Lower Phase I Basal Red Mud or Contaminated Travertines	1	1					1	1	2	1	1	1						
Totals	219	27	5	2	1	1	3	2	5	2	4	3	41	14	10	6	20	9

*From the 'Collapsed Cone' (Brain 1958 fig. 94; '10' and '11').

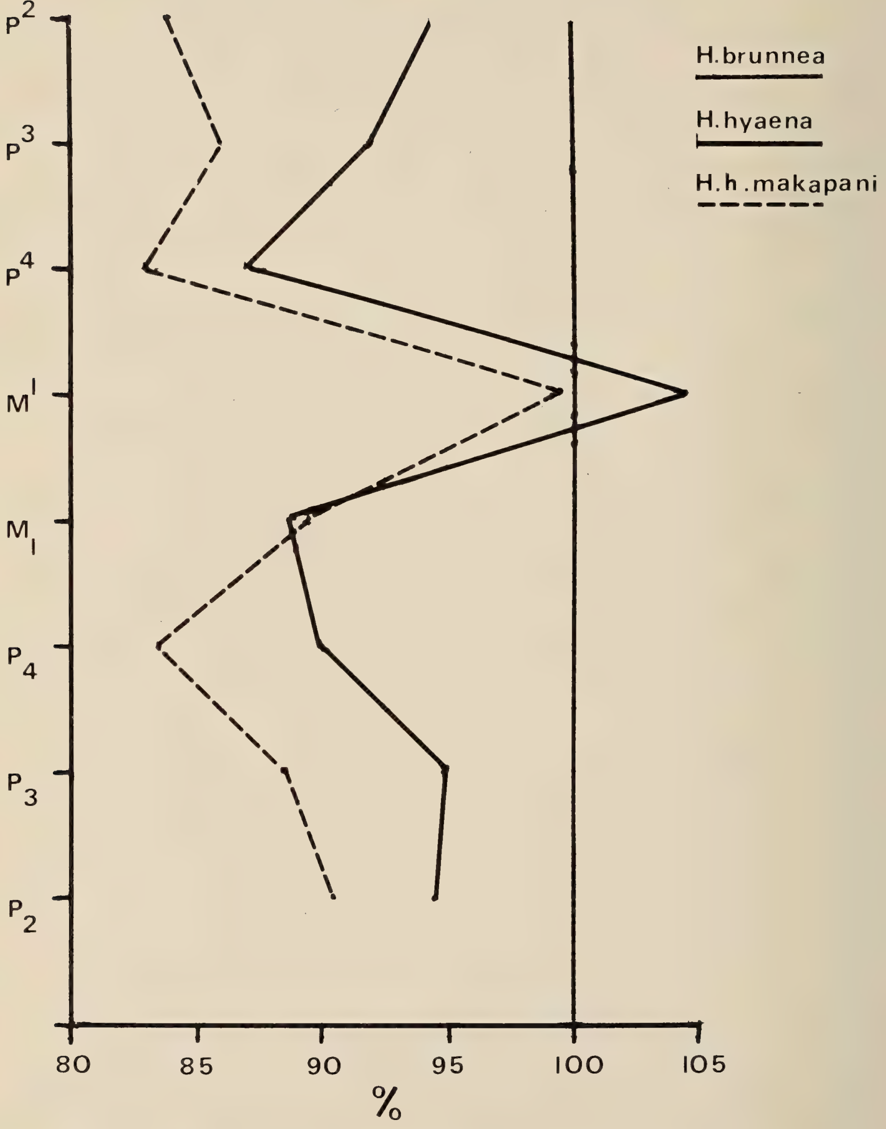

Fig. 1. Ratio diagram comparing mean tooth crown lengths of three hyaenas. Data from Kurtén, Toerien and this study.

closely related to the present-day striped hyaena of North Africa and Asia, and the other much better adapted to large prey. Therefore they might be seen to be compatible with the known bovids of that time. *Crocuta* makes its appearance for the first time in the Phase II Breccia in the form of one isolated left mandibular ramus belonging to a young individual (Fig. 3).

FELIDAE

Machaerodontinae

Homotherium cf. *nestianus* (Fig. 4). This skull and lower jaw was originally described as *Megantereon problematicus* Collings (1972) on the basis of its peculiarities as preserved. The specimen itself is laterally flattened and most of the top of the skull was removed during blasting operations by the lime-workers. In addition, and for reasons which are not entirely clear, different degrees of wear had occurred on each tooth row. Finally, the individual must have been quite old at death because of the total amount of tooth wear seen. Assignation to the species *nestianus* is tentative because of the excessive and unequal wear on the teeth and the lack of information about the missing portions of the skull. The upper canines are in fact serrated on both their front and rear edges, with the former being less distinctly serrated than the latter. The postcanine dentition comprises long, narrow $P\frac{4}{4}$, and much reduced $P\frac{3}{3}$. The lower canine is relatively small. The isolated single upper and lower canines from the Grey Breccia agree with those of the skull.

Felinae

Dinofelis barlowi (Broom). This animal shows some machaerodont tendencies, but is clearly much more closely allied to the true cats than is *Homotherium*. *D. barlowi* is one of the least specialized of the *Dinofelis* species, and supports the idea of the lower levels at Makapansgat being very old in terms of the South African Neogene. The following material is in the new collections:

(i) A large crushed and distorted skull in two blocks with some scattered metacarpals and other elements. Basal Red Mud.
(ii) Snout and lower jaw symphyseal region containing canines and incisors. Grey Breccia.
(iii) A detached naso-frontal region with part of right jugal arch and orbit plus part of the palate. No teeth. Grey Breccia.
(iv) A nearly complete right mandibular ramus containing all teeth except the incisors. Grey Breccia.
(v) A complete left ankle joint found in the vicinity of the skull ((i), above). Basal Red Mud.

Dinofelis sp. The proportions of this partial skeleton are very close to those of the modern leopard (*Panthera pardus*), but because positively identified skeletons of *D. barlowi* are not known it is realistic to leave this material unassigned as to species for the present. The degree of specialization of this skeleton seems less than in *D. diastemata* from Langebaanweg. The following material is in the new collections:

(i) A crushed and incomplete mandibular ramus without teeth. Grey Breccia.
(ii) A partial right mandibular ramus with only the roots of the canine and premolars preserved. Upper Phase I Breccia.
(iii) A large selection of postcranial bones belonging to one individual, in partial articulation. Basal Red Mud.
(iv) An isolated distal end of femur. Grey Breccia.

Representatives of each of the Makapansgat sabre-tooth cats occur in the Basal Red Mud. *D. barlowi* extends into the Grey Breccia and only the one specimen of *Dinofelis* is known in the Upper Phase I Breccia.

The association of a large hyena (*H.* cf. *brevirostris*) with a true sabre-tooth cat (*Homotherium* cf. *nestianus*) is probably an indication of the size of the prey species available to them. On these grounds it seems likely that the apparent disappearance of the large ungulates at the end of lower Phase I times caused the extinction of these carnivores as well. Quite clearly detailed analyses of the bovid fauna will tell us a great deal more than is presently known of their biology and may serve to dispute this subjective view of the happening of that time.

It is also believed that the more typical sabre-tooth cats had relatively weak hind limbs and short tails and because of this tended not to be open-country hunters. Thus they may have lain in wait for their prey in close cover and did not run it down in a chase. Certainly sabre-tooth cats were unlikely to have jumped on to the back of their prey, because their long thin canines would have been extremely vulnerable to breakage against the neural spines and other bony excrescences of the prey's skeleton. It is much more likely that sabre-tooth cats attacked the soft thinner-skinned underparts, or the throat, of their herbivore prey and this could be better effected by a short rush from behind cover (Cruickshank 1973).

HYSTRICIDAE

Xenohystrix crassidens is unusual in its extremely large size, and is a rare component of Plio-Pleistocene deposits. It is, however, the best represented porcupine at the Limeworks and all specimens are from mature adults. It has relatively brachydont dentition when compared with other porcupines, and both upper and lower cheek teeth appear to be rooted, as opposed to the semi-rooted condition seen in *Hystrix africaeaustralis*. The root pattern in *Hystrix makapanensis* is not seen clearly in any of the cheek teeth available for study, but the dentition is less brachydont than in *Xenohystrix crassidens* but also less hypsodont than in *Hystrix africaeaustralis*. In *X. crassidens* the diastema is relatively much shorter and the curvature of the incisors much more abrupt than in either of the others present in this deposit, which leads to the conclusion that this species had a shorter snout in comparison. With its more vertical orientation of the jaw adductor musculature and its brachydont dentition its diet could have been of softer vegetation than is usual in modern porcupines. This is supported by the fact that the roots of the cheek teeth close earlier in life and thus its teeth did not continue erupting for as long as is required in *H. africaeaustralis*. The rooted teeth of *X. crassidens* have their closest parallel in the atherurine porcupines of the tropical forests in south east Asia and in west and central Africa.

Hystrix makapanensis (Greenwood, 1958) is intermediate in size between *X. crassidens* and *H. africaeaustralis* but shows a strong tendency towards the specializations of the latter.

Hystrix africaeaustralis, some specimens of which were originally classified as *Hystrix* cf. *africaeaustralis* by Greenwood (1955), is identical in most respects to the living species and can thus be regarded as being an 'early form' of the South African porcupine. The presence of three species of porcupine living sympatrically in the one area is difficult to explain. *Xenohystrix* was probably a non-burrowing forest dweller similar to modern atherurines in this respect and the other two smaller species must have had contrasting ecological preferences. What they were is subject for speculation, but it can be expected that the *H. africaeaustralis* form living them must have had a mode of life very similar to its present-day descendants, tending to favour open-country savannah environments. All these species were likely to have been attractive prey. Today porcupines have few natural enemies barring man, leopard and other carnivores living under stress.

GENERAL

There is evidence from other sources (e.g. Maier 1970) that the area near to the Makapansgat cavern supported a body of permanent woodland, and this would, on analogy with modern times, be a strip of subtropical riverine bush and forest following the bed of the local river and even extending up into the mountains behind. This river runs very close to the Limeworks site today and if it were associated with a body of permanent forest then that forest must have approached very closely to the cavern entrance. Notwithstanding the presence of several forest-loving forms in the deposit, it is also clear that open plains were very close to hand and therefore the ecology of the Makapansgat region during Phase I times must have been very complex indeed. The present-day topography in the Makapansgat Valley is broken and varied and probably similar to the condition existing in the past. This may be one good explanation for the ecological complexity of the region as reflected in the fossils entombed in the deposits of the Limeworks.

It is also significant that while the Basal Red Mud has yielded a number of semi-articulated skeletons, no association of skeletal parts from single individuals is known from the Grey Breccia. This is understood to mean that during Basal Red Mud times the animals fell in through shafts or avens and were thus preserved.

The conditions under which accumulation of the Grey Breccia took place have been the subject of much speculation. It is probable that the bones in this level were accumulated through the activities of several agents, e.g. leopards, as suggested by Brain several times for the Swartkrans deposit, or largely by hominid activities, as the authors prefer. It is clear from a detailed study by J. M. M. that porcupines played a very minor part in assembling this vast collection, as the characters of modern *Hystrix africaeaustralis* accumulations are vastly different from this one.

The age of the deposit on the above groups

Hyaenidae

Three sites in Africa which have yielded hyaenas have also had radiometric dates assigned to them. They are Laetolil, Ileret and White Sands in the Omo Basin. The White Sands site has yielded the earliest dated record of *Crocuta crocuta* which is assessed at 2,75 m.y. (Howell *et al.* 1969: 81), and is the most important record because it refers to the latest form of hyaena at Makapansgat and means that the Phase II Breccia could have a maximum age of 2,75 m.y. b.p. The Grey and Upper Phase I Breccias are older, but by how much cannot be estimated on this evidence. We should like to stress the importance of the first appearance of *Crocuta* cf. *crocuta* in the Phase II breccia, as it is known that carnivores have much wider ecological tolerances than do herbivores It is therefore probable that because of their lesser sensitivity to environmental changes, the first appearance of a new carnivore species may well be almost simultaneous throughout a wide area, even in areas as widespread as east and southern Africa.

Felidae

Deposits at Koobi Fora and East Rudolph have been radiometrically dated and four felids are associated with these deposits. All are from zones 1 and 2 which have a time span of 1,3–2,6 m.y. (Maglio 1972). From these horizons the genera *Panthera*, *Dinofelis* and *Homotherium* are reported in association with *Megantereon eurynodon*. *Dinofelis* and *Panthera* are long-ranging genera. The E. Rudolf *Homotherium* has affinities with both *H. crenatidens* and *H. nestianus* (Maglio 1972; Meave Leakey pers. comm.), while *Megantereon eurynodon* is known also from Kromdraai (Faunal Site: Brain 1958) and the Upper Pliocene of China (Nihowan: Collings 1973). Therefore the levels at Makapansgat which have *Homotherium*, i.e. the Basal Red Mud and Grey Breccia, would seem to fall within the limits set by zones 1 and 2 at the E. Rudolf localities, with clearly a trend beyond the older date being probable, bearing in mind the postulated dates for the Phase II Breccias.

Hystricidae

The two species of *Hystrix* preserved at Makapansgat tell us little of the age of the deposit. From an examination of a cast of the only available specimen referred to cf. *Xenohystrix crassidens* reported by Bishop (1972) from the Chemeron Formation in East Africa it appears that the material is not assignable to this taxon and therefore adds little to our knowledge. The smaller porcupines from the datable East African deposits have not yet been identified and therefore cannot help.

CONCLUSIONS

On the basis of the foregoing, it would seem that the evidence would imply a maximum age of about 2,75 m.y. for the Phase II Breccias at Makapansgat Limeworks and if a limit of 1,8 m.y. is accepted as the lower boundary of the Pleistocene then most, if not all, of the Limeworks Deposit may be regarded, technically, as belonging to the Pliocene.

SUMMARY

Two hundred and twenty-five specimens of hyaenas ascribable to 3 species, 12 sabre-tooth and 'false sabre-tooth' specimens ascribable to 2 species and 71 porcupine specimens belonging to 3 species are briefly reviewed and their ecology and geological age are discussed.

From these speculations it is thought that the country immediately adjacent to the Makapansgat Limeworks at the time that the Lower Phase I levels were being deposited must have supported a much denser vegetation than at present, approximating to a subtropical riverine bush and forest.

On the basis of the meagre evidence presented, the only possible age estimate reached is for the Phase II Breccia which is not more than 2,75 m.y. old and therefore technically Pliocene.

ACKNOWLEDGEMENTS

None of this work could have been done by us without the deep personal knowledge of the Limeworks site shown by Dr J. W. Kitching, and so freely imparted. We should also like to acknowledge the help, criticism and assistance of Mr Brian Maguire, Dr C. K. Brain, Dr Q. B. Hendey, Prof. H. B. S. Cooke and Dr C. E. Gow. Dr J. M. Harris of the National Museums of Kenya made available information about the Chermeron Formation porcupines. The Council for Scientific and Industrial Research has provided funds to help the research programmes summarized here, in the form of personal grants to G.E.C., J.M.M. and R.M.R. and in the form of running grants to the Bernard Price Institute which sponsored them.

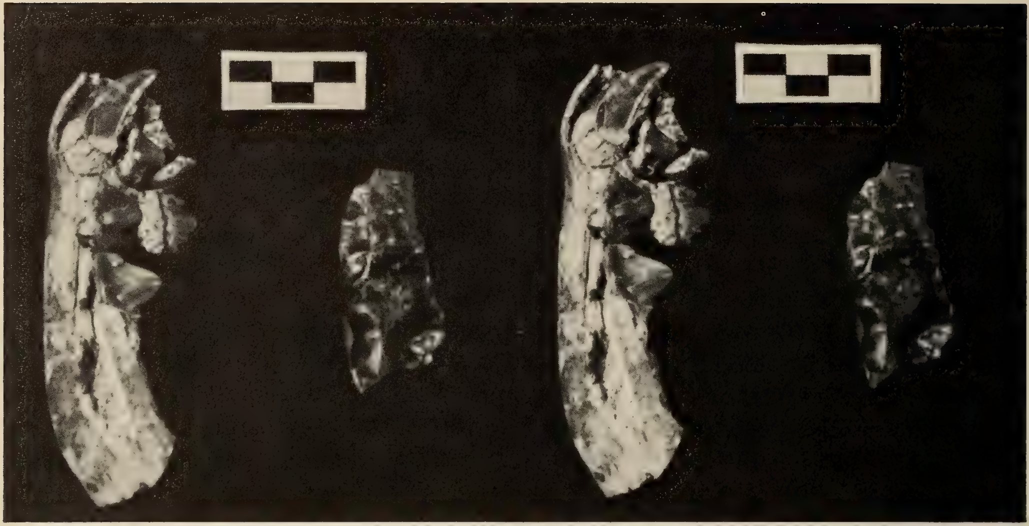

Fig. 2. Stereo photographs of maxillary (right) and mandibular (left) fragments of juvenile *H. h. makapani* to show milk dentition being replaced by permanent dentition. Specimens M603 and M2284 of the Bernard Price Institute for Palaeontological Research. Grey Breccia. (Metric scale).

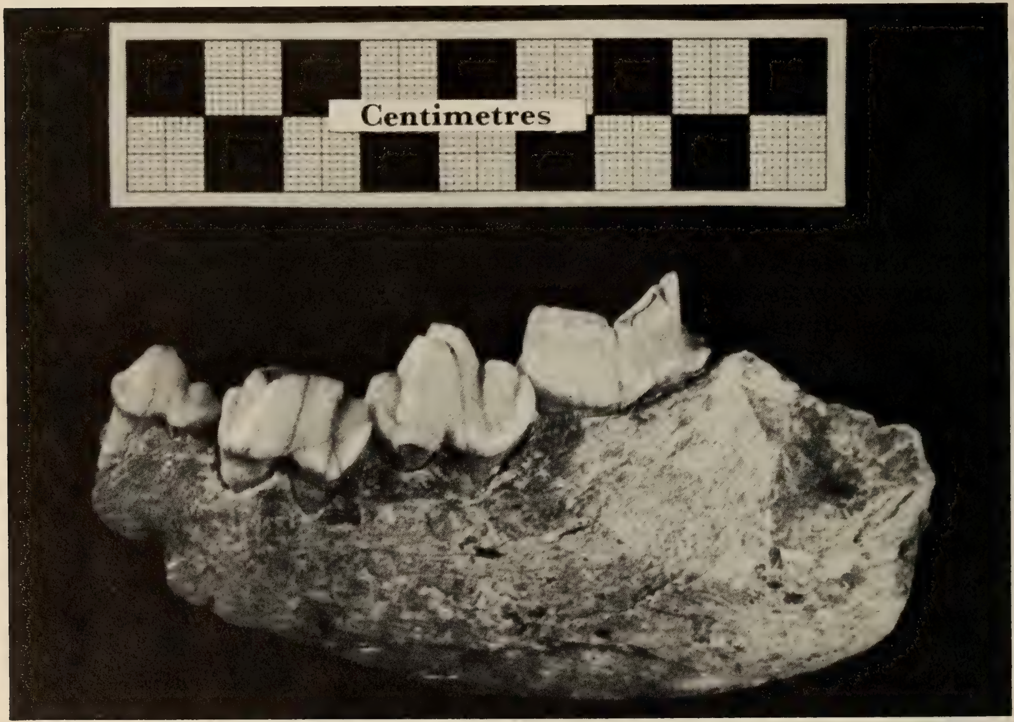

Fig. 3. Partial mandible of *Crocuta* cf. *crocuta*. Specimen M2567 of the Bernard Price Institute for Palaeontological Research. Phase II Breccia.

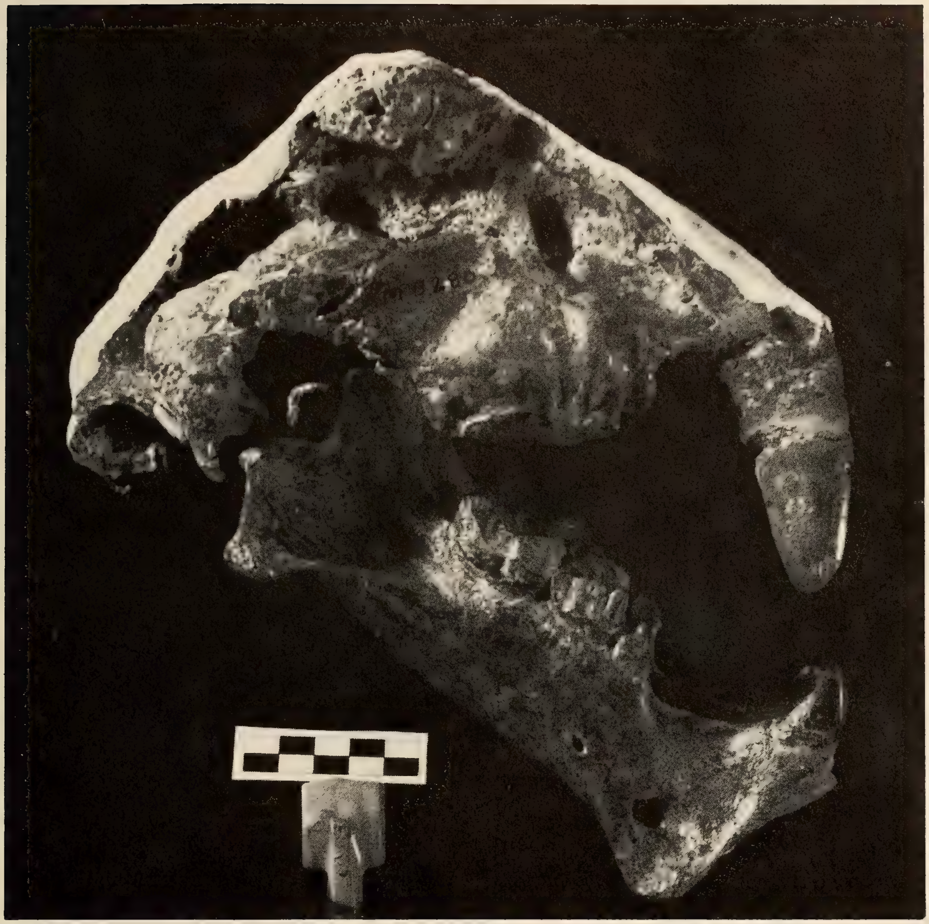

Fig. 4. Skull and mandible of *Homotherium* cf. *nestianus*. Specimen M8280 in the Bernard Price Institute. Basal Red Mud. (Metric scale.)

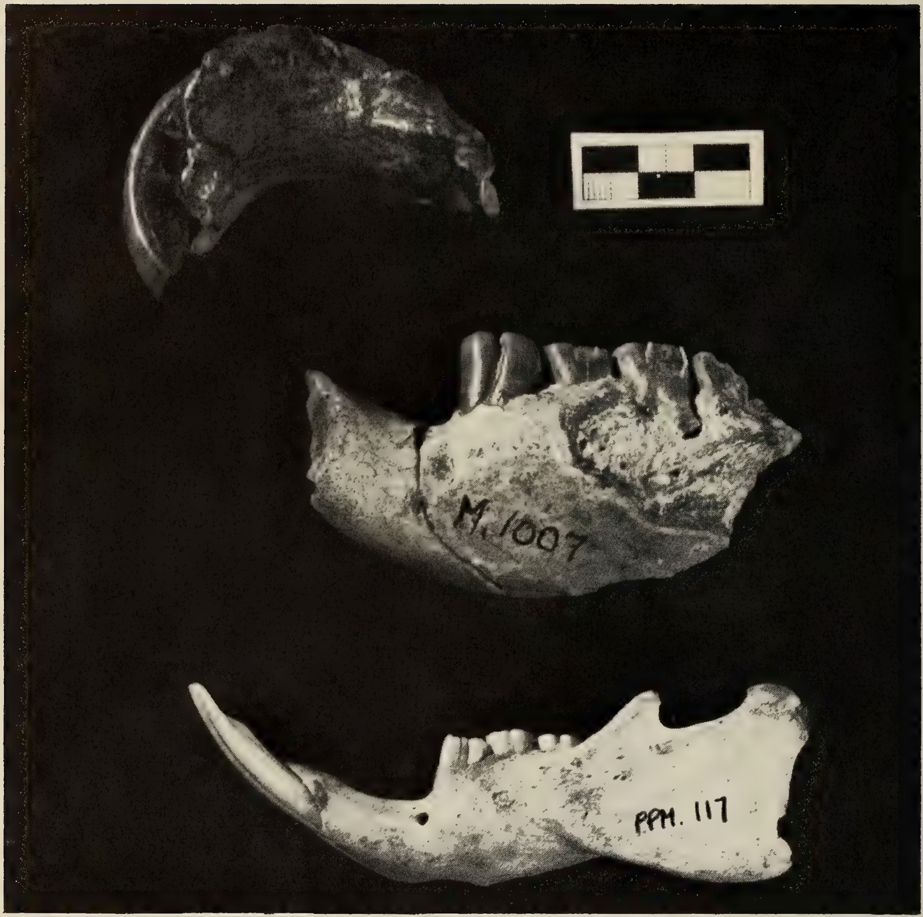

Fig. 5. Maxillary and mandibular fragments of *Xenohystrix crassidens* Greenwood (upper) compared with a lower jaw ramus of the extant porcupine, *Hystrix africaeaustralis* (lower). Dentitions of both mandibles at approximately the same stage of eruption. Specimens M.1006 and M.1007, in the Bernard Price Institute for Palaeontological Research, *Xenohystrix crassidens* from the Grey Breccia. Specimen PPM.117, *Hystrix africaeaustralis* in the Bernard Price Institute for Palaeontological Research. No locality data. (Metric scale.)

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PHYLOGENY OF THE RHINOCEROTIDS OF AFRICA

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(With 1 table)

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TEXT

The rhinocerotids as here understood comprise the *Epiaceratherium*—*Trigonias* group and its descendants. There are seven genera in Africa, as listed in Table 1. Four of them (*Brachypotherium*, *Aceratherium*, *Dicerorhinus* and *Chilotheridium*) emerge in the Early Miocene. As they represent full-fledged

Table 1. The rhinocerotids of Africa, distribution in space and time

	million years	*Brachypotherium*	*Aceratherium*		*Dicerorhinus*	*Chilotheridium*	*Diceros*	*Ceratotherium*	*Paradiceros*
Olduvai IV–Up. II		—	—		—	—	×	×	—
Lo. II–I	2–	—	—		—	—	—	×	—
Chemeron Fm.	4–2	—	—		—	—	—	×	—
Shungura Fm.	4–2	—	—		—	—	×	×	—
Mursi Fm.	4	—	—		—	—	×	×	—
Aterir Fm.	4–	—	—		—	—	—	×	—
Kanapoi	4	—	—		—	—	—	×	—
Langebaanweg		—	—		—	—	—	×	—
Lothagam Hill	6	×	—		—	—	—	×	—
Sahabi	6	×	—		—	—	—	—	—
Mpesida Beds	7	×	—		—	—	—	×	—
Ngorora Fm.	12–	×	×	or	×	×	—	—	—
Kirimun		—	×	or	×	×	—	—	—
Douaria	12	—	—		—	—	×	—	—
Alengerr Beds	14–12	—	×		×	—	—	—	—
Fort Ternan	14	—	—		—	—	—	—	×
Loperot	18	—	—		—	×	—	—	—
Sinda		×	×		—	—	—	—	—
Rusinga	18,5	×	×		×	×	—	—	—
Ombo		—	—		×	×	—	—	—
Napak	19	×	×		×	—	—	—	—
Bukwa II	23	×	—		?	×	—	—	—
Moghara		×	?		—	—	—	—	—

Proc. sth. Afr. Soc. Quat. Res. 1975.
Ann. S. Afr. Mus. **71**, 1976: 167–168, 1 table.

species different from their Eurasiatic counterparts they must have invaded Africa already in the Oligocene. *Brachypotherium* sprang from the Oligocene aceratheres. The African *Brachypotherium snowi* (Moghara, Egypt), *Brachypotherium heinzelini* (Bukwa II to Sinda, Zaïre), *Aceratherium acutirostratum* and *Dicerorhinus leakeyi* (both Napak to Alengerr) combine characters found in different Oligocene to Pliocene European species of the same genera, showing that the phylogeny in Africa was different from that in the rest of the Old World since the Oligocene. *Brachypotherium lewisi* (Ngorora to Lothagam Hill) is the latest representative of its genus in the world. *Chilotheridium pattersoni* is the African representative of the Eurasiatic *Chilotherium* div. spec., and differs in a combination of primitive (presence of metacarpal V, more slender metapodials) as well as progressive (small nasal horn, larger frontal air sinuses) characters. *Diceros* appears first in the Late Pliocene of North Africa (Douaria) and Eurasia (Pikermi, Samos, Maragha), and may be derived from the stock represented by *Paradiceros mukirii* (Fort Ternan). *Diceros bicornis* of Mursi, Ethiopia, has lower-crowned molars than the modern species (Shungura to Recent). *Ceratotherium praecox* (Mpesida to Mursi) is the direct ancestor of *Ceratotherium simum* (Shungura to Recent), and split off from the *Diceros* stock in the Late Miocene.

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THE FOSSIL HISTORY OF *RAPHICERUS* H. SMITH, 1827 (BOVIDAE, MAMMALIA) IN THE CAPE BIOTIC ZONE

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(With 5 figures, 1 map and 2 tables)

ABSTRACT

The present distribution and to some extent the fossil record of *R. melanotis* suggest it may have evolved in the Cape Biotic Zone, perhaps in response to the substantially different environmental conditions which characterized much of the later (and ?mid) Pleistocene and which supported large populations of now extinct endemic or near endemic grazing species. *R. campestris* appeared in the Zone no later than the earlier part of the Upper Pleistocene, but clear evidence for its essentially modern distribution and abundance is so far restricted to very recent Holocene contexts. Perhaps it was similarly distributed and abundant in climatically comparable portions of earlier interglacials. There is some evidence from dental measurements to suggest that *Raphicerus* spp. may have been significantly larger during especially cold intervals in the Zone, but this requires further investigation. There is also some evidence for selective predation on *Raphicerus* individuals of different ages at various sites, but this too requires further research for secure demonstration. Limited evidence suggests that at least Later Stone Age peoples did not prey selectively on animals of either sex. The chances of obtaining additional information both from and about *Raphicerus* in the Cape Biotic Zone are excellent since it occurs in high frequency in virtually all local palaeontological and archaeological sites.

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INTRODUCTION

The far south-western corner of the African continent is distinguished from the rest of sub-Saharan Africa by its warm temperate climate, unique 'fynbos' ('Cape Macchia') vegetation, and endemic fauna. Its biological distinctiveness has been recognized by several authors, for example, by Meester (1965) who suggested the name 'South-West Cape Biotic Zone', shortened by Hendey (1974: 16) to 'Cape Biotic Zone'. As defined by Hendey and used here, the 'Cape Biotic Zone' includes three subdivisions (Map 1): (1) the south-western Cape *sensu stricto*; (2) the southern Cape; and (3) the Cape Folded Mountains.

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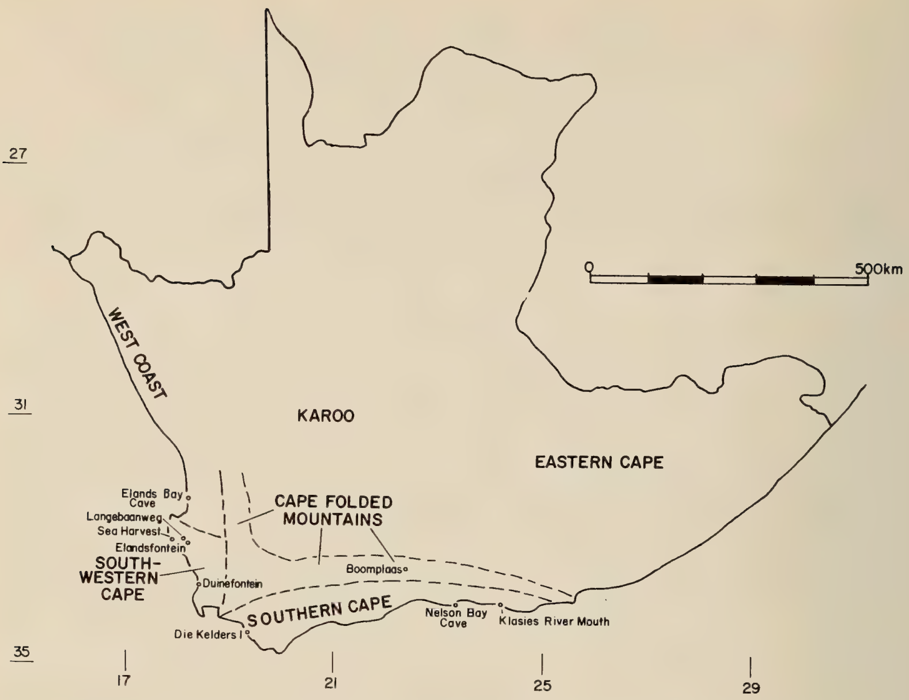
Ann. S. Afr. Mus. **71**, 1976: 169–191, 5 figs, 1 map, 2 tables.



Map 1. The schematic extent of the major subdivisions of the Cape Biotic Zone (after Hendey 1974:7) and the approximate locations of the principal sites providing *Raphicerus* samples relevant to this paper.

Historically, the south-western Cape has been differentiated from the southern Cape by more seasonally restricted (winter) rainfall and by a relatively impoverished mammalian fauna (see Klein 1974*a*, table 1). Evidence from sites such as Sea Harvest (Hendey 1974, table 6), Melkbos (Hendey 1968; Klein, unpublished), and Swartklip (Hendey & Hendey 1968; Klein 1975*a*) in the south-western Cape and Die Kelders I (Klein 1975*b*), Nelson Bay Cave (Klein 1972*a*), and Klasies River Mouth (Klein 1974*b*) in the southern Cape suggests the two areas were more alike faunistically in the late Pleistocene, perhaps in part because of greater climatic similarity and in part because faunal interchange was facilitated by exposure of the continental shelf during periods of lowered sea-level. The late Pleistocene fauna of the two areas is further notable for a number of extinct taxa (Klein 1974*a*), including at least three forms which at that time were almost certainly Cape Biotic Zone endemics: a small springbok (*Antidorcas australis*), a wildebeest at least subspecifically distinct from the extant *Connochaetes gnou*, and a reedbuck at least subspecifically distinct from the extant *Redunca arundinum*. Historically recorded endemics include (after Meester 1965: 91) four rodents (*Bathyergus suillus*, *Praomys verreauxi*, *Acomys subspinosus*, and *Tatera afra*) and two large mammals—the blue antelope (*Hippotragus leucophaeus*) and the bontebok (*Damaliscus dorcas dorcas*). In the late Pleistocene, the blue antelope occurred somewhat outside the area of the Cape Biotic Zone as defined here (Klein 1974*c*), suggesting the possibility that the boundaries of the Zone have varied over time, presumably in response to climatic change.

In addition to the endemic mammals listed above, the grysbok (*Raphicerus melanotis*) is largely restricted to the Cape Biotic Zone, where it overlaps with its much more widespread relative, the steenbok (*Raphicerus campestris*). The purpose of this paper is to summarize the fossil history of these two species in the Cape Biotic Zone, with particular emphasis on the later Pleistocene and Holocene.

THE MODERN SPECIES OF *RAPHICERUS*

In addition to *R. melanotis* and *R. campestris*, most authorities recognize yet a third extant species of *Raphicerus*, *R. sharpei*, known popularly as Sharpe's grysbok. In contexts where *R. sharpei* and *R. melanotis* are both discussed, the latter is known as the Cape grysbok. Some authors, for example, Haltenorth (1963: 78) and Smithers (1971: 221) consider the two grysboks to be distinct only at the subspecies level (*R. melanotis melanotis* and *R. m. sharpei*), but the more conventional specific distinction has been retained here.

Individuals of all three species of *Raphicerus* are small (7–14 kg), inconspicuous, non-gregarious antelopes (Dorst & Dandelot 1970: 264, 266; Bigalke 1974: 833; Smithers 1971: 220, 222; Astley Maberley 1967: 129–138). Unlike many larger, gregarious species, they are still found in good numbers over large parts of their historic ranges. As already indicated, *R. melanotis* is largely confined to the Cape Biotic Zone, although it is also distributed in adjacent areas of the south-eastern Cape (Bigalke & Bateman 1962, map 4). *R. campestris* is far more widespread, occurring with minor discontinuities over nearly all of southern Africa and also in parts of Kenya and Tanzania in East Africa (Ansell 1971: 66; see also Dorst & Dandelot 1970: 269). In the Cape Biotic Zone, it is most numerous in the south-western Cape where it probably outnumbers *R. melanotis*. In the southern Cape, it is generally less numerous than *R. melanotis*, and in fact is probably absent altogether from some areas with especially heavy cover (for example, portions of the Knysna Forest) where *R. melanotis* is fairly common (pers. obs.). In southern Africa, *R. sharpei* occurs no further south than Swaziland, extending from there into southern Tanzania (Ansell 1971: 67; see also Dorst & Dandelot 1970: 269). It therefore nowhere overlaps *R. melanotis* and is sympatric with *R. campestris* only in the north-eastern portions of the latter's range.

Survival for all three species of *Raphicerus* requires the presence of adequate cover, but the steenbok exhibits a clear tendency to inhabit more open country than the grysboks (Bigalke 1972: 176). All three may be broadly characterized as selective browsers (Jarman 1974: 223), but perhaps in keeping with its preference for more open environments, the steenbok apparently incorporates a higher proportion of grass into its diet (Smithers 1971: 221, 222; Hoffmann & Stewart 1972: 228).

The three species are fairly easy to tell apart on the basis of pelage and other external characters (Dorst & Dandelot 1970: 264, 266). There are no published criteria for distinguishing them on hard parts, but A. W. Gentry (pers. comm.) has suggested several cranial characters which together allow

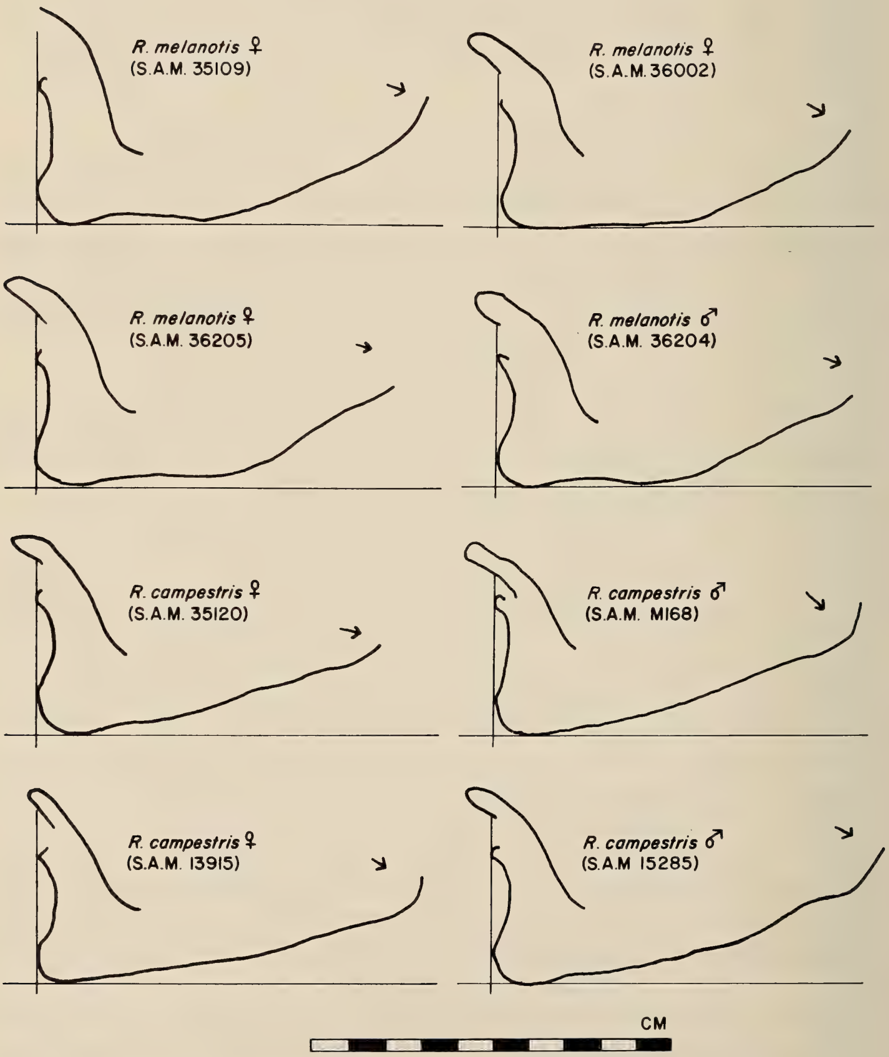


Fig. 1. Outlines of left mandibles of *Raphicerus melanotis* and *R. campestris*, illustrating the differences between the two species in the configuration of the inferior margin of the horizontal ramus. An arrow indicates the approximate position of the canine in each case (after originals by K. Scott).

complete separation of *R. campestris* from *R. melanotis*. These include a more upright insertion of the horncores in *R. campestris* as well as significantly broader ethmoidal fissures, smaller preorbital fossae, and larger auditory bullae than in *R. melanotis*. Although it may be impossible to distinguish them on dental morphology, K. Scott (pers. comm.) has observed that the configuration of the inferior margin of the mandible differs significantly between the two species (Fig. 1): in *R. campestris* it tends to be fairly straight, while in *R. melanotis* it is markedly convex. This difference is well marked in animals of all ages, but seems especially clear in juveniles. *R. sharpei* probably resembles *R. melanotis* in mandibular shape, but the author has seen too few *R. sharpei* specimens to be sure. This mandibular difference is particularly useful in dealing with fossil samples because the relevant portion of the mandible is generally preserved in high frequency versus other cranial elements on which distinctions may be made. Mandible configuration was the principal and in most cases the only feature which could be used to calculate the relative frequencies of grysbok and steenbok in the fossil samples discussed below.

In an attempt to establish further cranial characters which might allow separation of *R. campestris* and *R. melanotis*, measurements were made on dental rows and on the diastemata of a series of comparative specimens of each species housed in the South African Museum. The means, standard deviations, and numbers of specimens involved are recorded in Appendix 1 (see also Figs 2–3). The results of 'Student's t' tests for the significance of differences between means, where such differences were significant at the 0,05 level or below, are recorded in Appendix 2.

All the specimens in the Museum's collection were either of unknown provenience or were derived from the Cape Biotic Zone so that it was not possible to test for geographic variability in either species. Student's 't' tests run to compare the sexes within each species revealed no significant differences in mean dental dimensions, perhaps because the samples involved were too small. It is thought that the samples were large enough, however, to conclude that sex-related dental size differences, if any, are probably small in magnitude. This is the justification for ignoring sex in comparing the *R. melanotis* and *R. campestris* comparative samples to the fossil ones (below) in which sex cannot be established in any case.

The results suggest that the mean length of the diastema (measured from the posterior margin of the canine alveolus to the anterior margin of the alveolus for P_2) may be used as a nearly discrete feature to separate *R. campestris* from *R. melanotis* (at least as adults). The relevant Dice-Leraas diagram in Figure 2 (see also Appendices 1–2) shows that the mean diastema length in *R. campestris* is significantly greater than the mean length in *R. melanotis*, while in the comparative samples and in fossil samples from the site of Die Kelders I (where *R. campestris* mandibles were sorted from those of *R. melanotis* on the degree of curvature of the inferior margin of the horizontal ramus), there is little or no overlap in observed ranges. The observed ranges do overlap

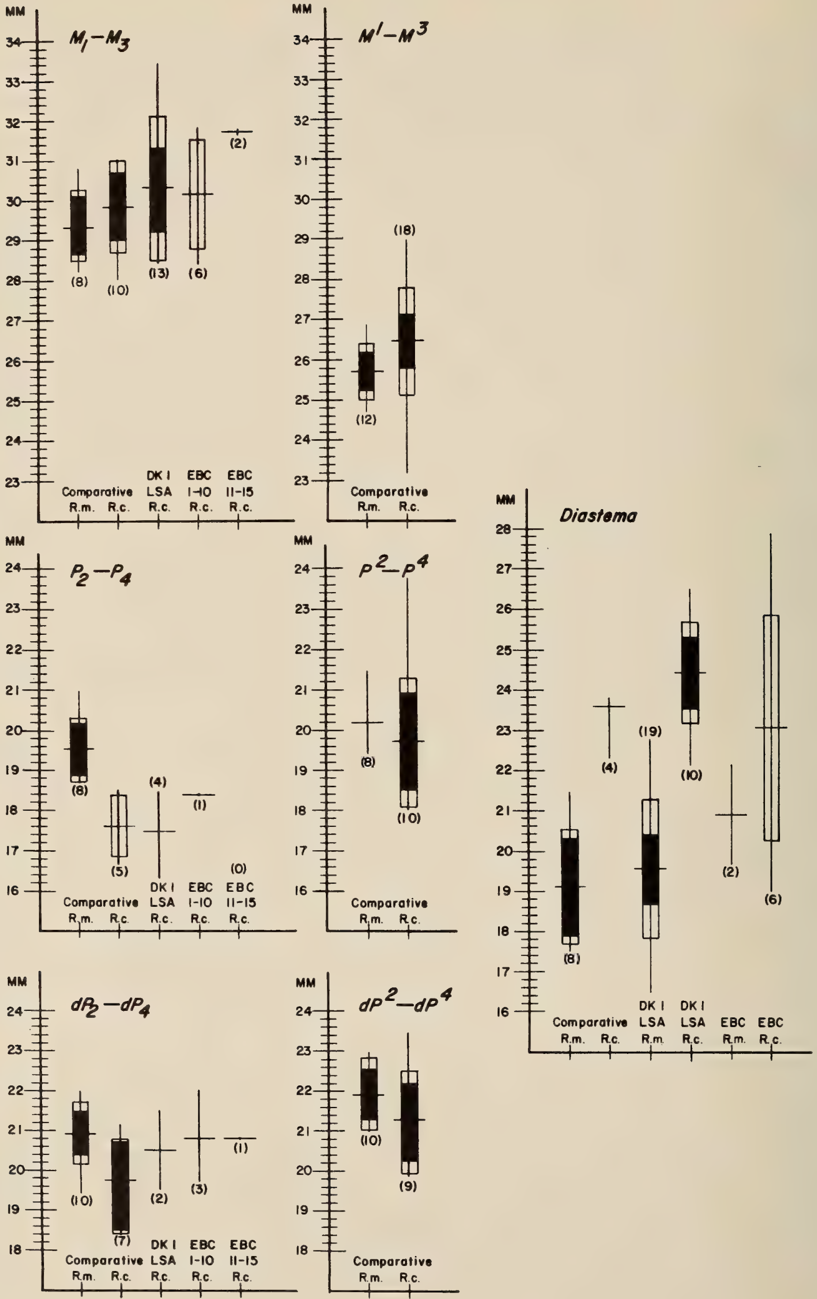

MM
M_1-M_3
(8)
(10)
(13)
(6)
(2)
Comparative R.m. R.c.
DK I LSA R.c.
EBC 1-10 R.c.
EBC 11-15 R.c.
M^1-M^3
(12)
(18)
Comparative R.m. R.c.
P_2-P_4
(8)
(5)
(4)
(1)
(0)
P^2-P^4
(8)
(10)
dP_2-dP_4
(10)
(7)
(2)
(3)
(1)
dP^2-dP^4
(10)
(9)
Diastema
(8)
(4)
(19)
(10)
(2)
(6)
Comparative R.m. R.c.
DK I LSA R.m.
DK I LSA R.c.
EBC R.m.
EBC R.c.

Fig. 2.

substantially in a second set of fossil samples from Elands Bay Cave (Fig. 2), but the Elands Bay samples involved are small and contrast with the comparative and Die Kelders samples to such an extent that it seems possible a recording or measuring error is responsible.

The premolar and molar row lengths of *Raphicerus* specimens were measured always at the level of the occlusal surface. A complicating factor here is that the mean measurements may change somewhat as the teeth wear, and the samples involved were too small to test for this directly. However, the author believes that changes with wear are probably not substantial, since as one tooth within a row shortens with wear, another tends to lengthen correspondingly, preventing row lengths from changing significantly during the life of an individual. Additionally, the samples on which measurements were made were roughly comparable in their age frequency composition. As a consequence, the author thinks that any statistically significant differences observed in mean dental row lengths between comparative *R. campestris* and *R. melanotis* or between either and the fossil samples discussed below are probably open to non-trivial interpretation.

The measurements indicate that the mean length of the molar row is probably greater in *R. campestris*, while the mean length of the premolar row is probably greater in *R. melanotis*, though for both dental rows the species' ranges overlap substantially, and with the present data, a statistically significant mean difference is demonstrable only for dP_2–dP_4 and P_2–P_4 (longer in *R. melanotis*) (see Fig. 2 and Appendices 1–2). The mean premolar row/molar row length ratios are significantly smaller in *R. campestris* than in *R. melanotis* (Appendices 1–2), in keeping with the hypothesis that the steenbok has a shorter mean premolar row and a longer mean molar row. This finding further makes sense in view of the somewhat greater propensity of the steenbok to incorporate

Fig. 2. Dice-Leraas diagrams (modified following procedures discussed by Simpson *et al.* 1960: 355) for the comparison of mean dental row and diastema lengths between *Raphicerus melanotis* and *R. campestris* and among *R. campestris* samples from various Cape Biotic Zone sites. (R. m. = *R. melanotis*; R.c. = *R. campestris*; DK 1 = Die Kelders 1; EBC = Elands Bay Cave). Since the two species cannot be securely separated on maxillary characters, only mandibular dental rows are considered in comparisons involving fossil samples. The various samples are arranged so that older ones are generally to the right (see Table 1 for the geologic ages of the samples). Vertical lines show observed ranges; open rectangles mark standard deviations, with solid black indicating the 95 per cent confidence intervals for the mean. The means are indicated by horizontal lines, and the number of specimens in each sample is shown in parentheses.

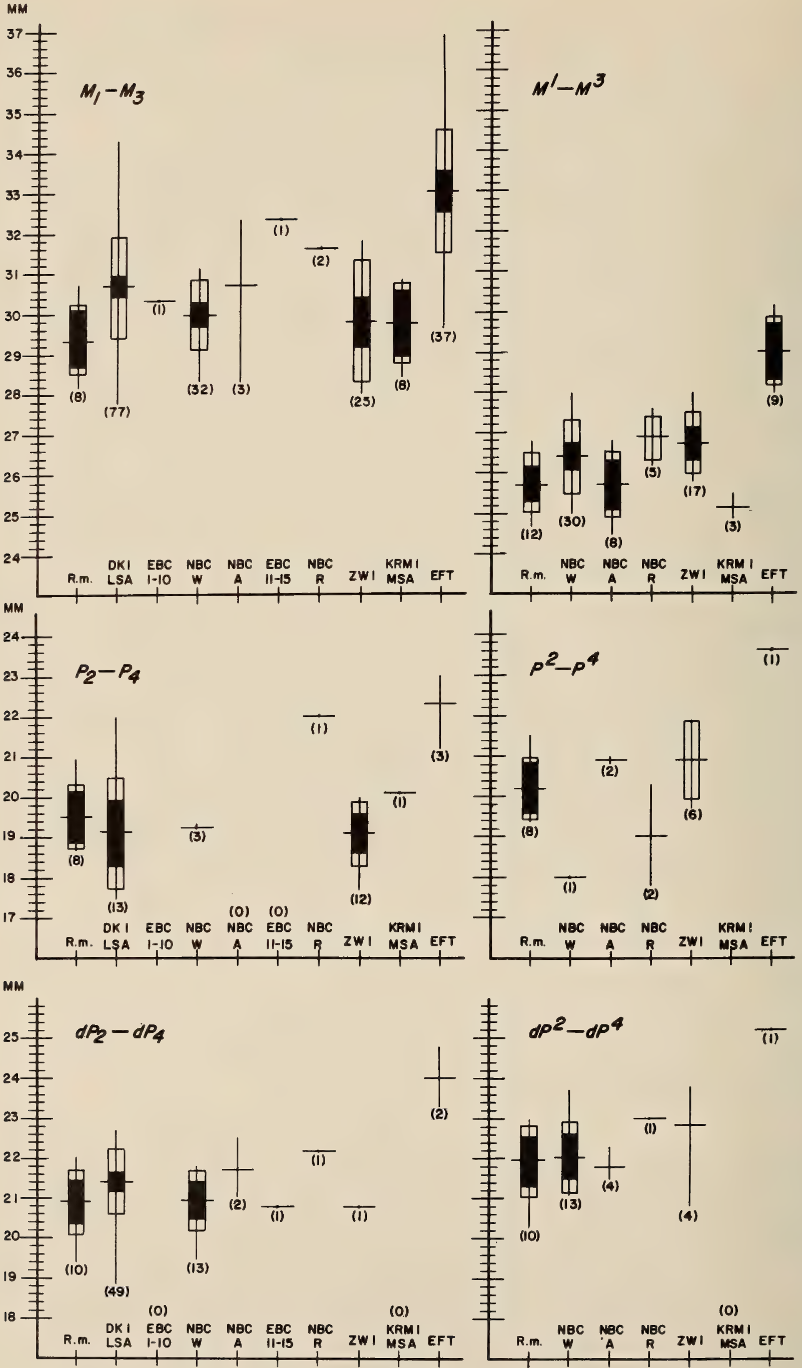

MM
37
36
35
34
33
32
31
30
29
28
27
26
25
24
M_1-M_3
(8)
(77)
(1)
(32)
(3)
(1)
(2)
(25)
(8)
(37)
R.m.
DK I LSA
EBC 1-10
NBC W
NBC A
EBC 11-15
NBC R
ZW I
KRM I MSA
EFT
M^1-M^3
(12)
(30)
(8)
(5)
(17)
(3)
(9)
R.m.
NBC W
NBC A
NBC R
ZW I
KRM I MSA
EFT
MM
24
23
22
21
20
19
18
17
P_2-P_4
(8)
(13)
(3)
(0)
(0)
(1)
(12)
(1)
(3)
R.m.
DK I LSA
EBC 1-10
NBC W
NBC A
EBC 11-15
NBC R
ZW I
KRM I MSA
EFT
P^2-P^4
(8)
(1)
(2)
(2)
(6)
(1)
R.m.
NBC W
NBC A
NBC R
ZW I
KRM I MSA
EFT
MM
25
24
23
22
21
20
19
18
dP_2-dP_4
(10)
(49)
(0)
(13)
(2)
(1)
(1)
(1)
(0)
(2)
R.m.
DK I LSA
EBC 1-10
NBC W
NBC A
EBC 11-15
NBC R
ZW I
KRM I MSA
EFT
dP^2-dP^4
(10)
(13)
(4)
(1)
(4)
(0)
(1)
R.m.
NBC W
NBC A
NBC R
ZW I
KRM I MSA
EFT

Fig. 3.

grass in its diet. It is an easily demonstrable generalization for bovids that grazing species usually have longer molar rows relative to premolar rows than browsing species.

FOSSIL *RAPHICERUS*

Although as yet undescribed specimens from the Pliocene locality of Langebaanweg in the south-western Cape suggest that *Raphicerus* may have been in existence as long as 4 to 5 million years ago (Hendey 1973), the genus has a remarkably poor fossil record (Gentry, in press). Among other things, it is not possible to say when the various species of *Raphicerus* diverged. Material from the Krugersdorp australopithecine site of Swartkrans includes mandibles which are very similar in horizontal ramus configuration to those of *R. campestris* (pers. obs. on material kindly shown to the author by E. Vrba), while the (?somewhat later) mid-Pleistocene locality of Elandsfontein in the south-western Cape has provided remains of a very large species of *Raphicerus*, which in the relatively great inclination of the horncores and the convex shape of the inferior margin of the mandible (Fig. 4) is more reminiscent of *R. melanotis*. This may indicate that the lines leading to *R. campestris* and *R. melanotis* had already diverged by mid-Pleistocene times, with the *R. melanotis* lineage perhaps evolving in the Cape Biotic Zone. Whatever the case, the great size of the Elandsfontein species relative not only to modern *R. melanotis* and *R. campestris*, but also to samples from such earlier Upper Pleistocene sites as Klasies River Mouth Cave I and Swartklip I (Fig. 3), in combination with the tendency of its horncores to display an irregular (vs. relatively rounded) cross-section, is another indication of the fact that the basic Elandsfontein

Fig. 3. Dice-Leraas diagrams (modified following procedures discussed by Simpson *et al.* 1960: 355) for the comparison of mean dental row and diastema lengths among samples of *Raphicerus melanotis* from various Cape Biotic Zone sites. (R. m. = comparative *R. melanotis*; DK 1 = Die Kelders 1; EBC = Elands Bay Cave; NBC W, A, R = Nelson Bay Cave Wilton, Albany, and Robberg; ZW 1 = Swartklip 1; KRM = Klasies River Mouth Cave 1; EFT = Elandsfontein. The Elandsfontein sample is actually derived from an as yet undescribed species of *Raphicerus*, but is included here since the species may be ancestral to *R. melanotis*). The sites are arranged so that older ones are generally to the right (see Table 1 for the geological ages of the samples). Since criteria have not yet been developed to separate *R. melanotis* and *R. campestris* on maxillary characters, for sites where both are clearly present (see Table 1), only mandibular parameters are presented in the diagrams. Vertical lines show observed ranges; open rectangles mark standard deviations, with solid black indicating the 95 per cent confidence intervals for the mean. The means are indicated by horizontal lines, and the number of specimens in each sample is shown in parentheses.

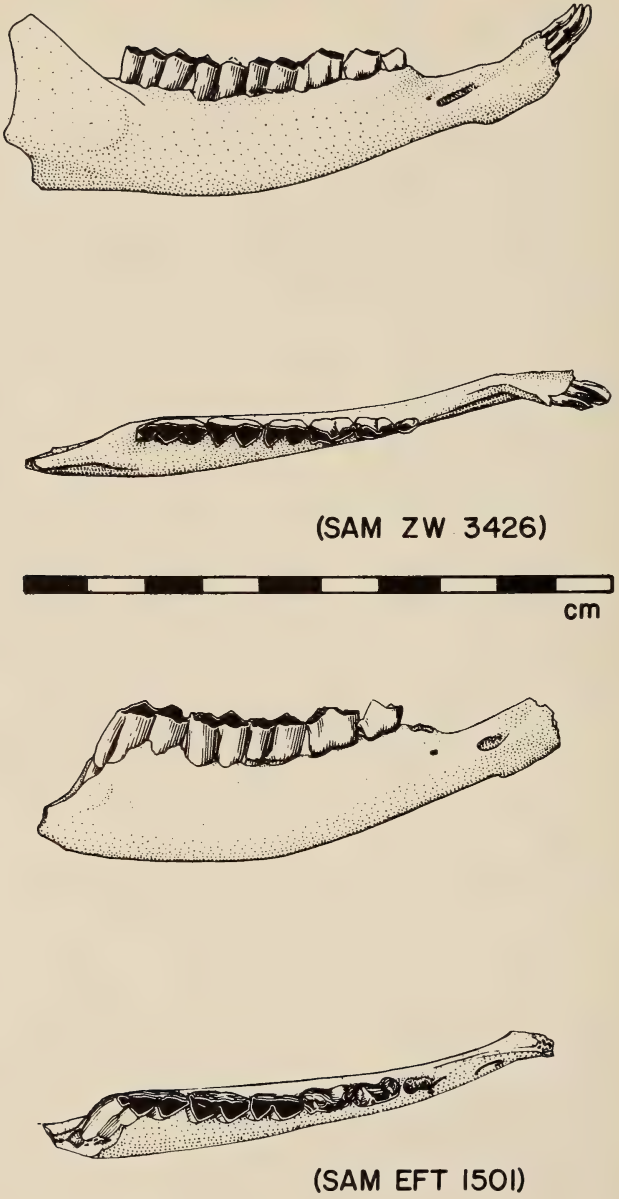


Fig. 4. Right mandibles of *Raphicerus melanotis* from Swartklip 1 (top) and *Raphicerus* sp. from Elandsfontein (bottom) (drawings by K. Scott).

fauna, and perhaps also the 'Saldanha Skull', antedates the Upper Pleistocene by a significant time interval (Klein 1973).

Fossil remains, especially mandibles, indistinguishable from those of modern *R. melanotis* are well known in the Cape Biotic Zone from a series of earlier Upper Pleistocene sites in both the south-western and southern Cape (Table 1, Map 1). However, only one of the sites—the Sea Harvest locality at Saldanha Bay—has provided remains attributable to *R. campestris* and then in circumstance that suggest the species may have been less numerous near Saldanha than *R. melanotis.* At present, *R. campestris* is numerically dominant in the area. The absence of steenbok at Klasies I was perhaps to be expected since the site is in an area today (near the eastern margin of the Knysna Forest) where steenbok are very rare, and both the Klasies sediments and the fauna taken as a whole suggest an environment similar to the modern one at the time the fauna accumulated (the Last Interglacial). The absence of steenbok at the remaining sites (Die Kelders, Swartklip and Duinefontein) is more surprising since the species occurs in fair numbers near each today. It is unlikely that sampling error is involved—if, for example, the ratio of grysbok to steenbok in the earlier Upper Pleistocene near Die Kelders were assumed to be the same as in the late Holocene sample from the site, that is, roughly 3 : 1, the binomial probability of encountering 26 identifiable grysbok and no steenbok would be considerably less than 0,001. Even if the ratio were 10 : 1 in favour of grysbok, the probability of finding 26 grysbok and no steenbok in the earlier Upper Pleistocene sample would be only 0,065. The full faunal lists of Die Kelders, Swartklip, Duinefontein and Sea Harvest contain taxa (especially *Antidorcas* and *Connochaetes* in fair numbers) which suggest a substantially different vegetation cover than the modern one. More particularly, a much larger-than-modern grass component is implied, and while there is nothing *a priori* in a grassier environment to exclude *R. campestris* (quite the reverse), it seems possible that the particular conditions which prevailed placed it at a distinct competitive disadvantage relative to *R. melanotis.* Such peculiar (vs. any modern) environmental conditions may in fact have occupied a far larger proportion of Quaternary time than have modern ones and may even be the ones in which *R. melanotis* evolved, perhaps as part of a faunal complex involving the now extinct, larger Cape Biotic Zone endemics mentioned earlier.

Mid-Upper Pleistocene faunas in the Cape Biotic Zone are essentially unknown at present, but on-going excavations directed by H. J. Deacon at Boomplaas Cave near Oudtshoorn promise to fill the gap in the near future. Terminal Pleistocene faunal samples containing specimens of *Raphicerus* are known from Elands Bay Cave in the south-western Cape (technically, just beyond its northern boundary as defined here) and Nelson Bay Cave in the southern Cape. The Nelson Bay samples do not allow estimates of the relative frequencies of *R. melanotis* and *R. campestris*, but the Elands Bay samples indicate that *R. melanotis* and *R. campestris* may have been about equally common near that site (Table 1). In recent times, *R. campestris* has been far

TABLE 1. Frequencies of *Raphicerus* spp. in Upper Pleistocene and Holocene sites in the Cape Biotic Zone (for the locations of the sites, see Map 1).

SITE	GEOLOGICAL AGE[a] (AND NATURE OF EVIDENCE)	MINIMUM NUMBERS OF INDIVIDUALS IDENTIFIABLE AS:[b, c] *R. melanotis*	*R. campestris*	*Raphicerus* spp.	TYPE OF SITE (AND REFERENCES)
Sea Harvest	Late Last Interglacial (?) [14–C > 40 000 (UW–282) & geological inference]	3	1	9	Palaeontological (? carnivore accumulation) (Hendey 1974: passim; Klein unpublished; Butzer unpublished)
Duinefontein (Melkbos)	Late Last Interglacial (geological inference)	many	few or none	many	Palaeontological (? carnivore accumulation) (Klein and Butzer unpublished)
Swartklip I	Late Last Interglacial (?) [14–C > 40 000 (I–6 840) & geological inference]	17	0	29	Palaeontological (carnivore accumulation) (Hendey & Hendey 1968; Klein 1975a; Butzer unpublished)
Klasies River Mouth Cave 1 ‘MSA’	Last Interglacial (geological inference)	16	0	53	Archaeological (Wymer & Singer 1972; Klein 1974*b* and unpublished; Butzer unpublished)
Die Kelders I ‘MSA’	Earlier Last Glacial (geological inference)	26	0	125	Archaeological (Tankard & Schweitzer 1974 and in press; Klein, 1975*b*)
Die Kelders I ‘LSA’	*c.* 2 000–1 500 B.P. (14–C)	98	30	156	Archaeological (Schweitzer 1970, 1974)
Elandsbay Cave levels 11–15	*c.* 11 000–9 600 B.P. (14–C)	10	9	37	Archaeological (Parkington 1972 and in preparation; Klein unpublished)
Elandsbay Cave levels 1–10	*c.* 3 500–0 B.P. (14–C)	0	11	28	Archaeological (references as for Elands Bay 11–15)
Nelson Bay Cave Robberg levels	*c.* 18 000–14 000 B.P. (14–C)	0	0	14	Archaeological (Klein 1972*a*, 1972*b*, 1974*b*; Butzer 1973; Fairhall & Young 1973).
Nelson Bay Cave Albany Levels	*c.* 12 000–8 000 B.P. (14–C)	3	0	33	Archaeological (references as for Nelson Bay Robberg)
Nelson Bay Cave ‘Pre-Climax and Climax’ Wilton Levels	*c.* 8 000–5 000 B.P. (14–C)	28	0	100	Archaeological (references a sfor Nelson Bay Robberg)
Nelson Bay	*c.* 3 000–1 500 B.P. (14–C)	4	0	21	Archaeological (Inskeep and Klein, unpublished)

[a] As used here, the Last Interglacial spans the interval from roughly 125 000 to 75 000 B.P. It is followed immediately by the Last Glacial which terminates at approximately 10 000 B.P. The Last Interglacial and Last Glacial together comprise the Upper Pleistocene.

[b] The numbers of *Raphicerus melanotis* and *R. campestris* individuals were calculated from identifiable mandible fragments. The numbers of *Raphicerus* spp. were calculated using the same mandible fragments, plus maxillary dentitions and mandible fragments which were not identifiable

more common, a fact which is apparently reflected in the late Holocene sample from the same locality (Table 1). As at Sea Harvest, Swartklip, and Duinefontein, the species accompanying *Raphicerus* in the very late Pleistocene levels of Elands Bay suggest a vegetation cover with a greater-than-present grass component. Once again, however, the particular conditions that prevailed were ones in which *R. melanotis* was able to compete more effectively with *R. campestris* than it can in the area today.

The various Holocene samples—from Elands Bay, Die Kelders and Nelson Bay—suggest that at least by the late Holocene the essentially modern distributions and relative frequencies of *Raphicerus* spp. had become established in the Cape Biotic Zone. More particularly, the late Holocene fossil samples imply that as at present, *R. campestris* became less common and *R. melanotis* more common along the coast from north-west to south-east. Supplementary faunal data from the nearly complete Holocene sequence at Nelson Bay indicate that the Holocene environment there was variable, but consistently high frequencies of such creatures as bushbuck (*Tragelaphus scriptus*) and bushpig (*Potamochoerus porcus*) in the Nelson Bay Holocene deposits indicate the more or less continuous occurrence of the relatively closed vegetational surroundings known to be more favourable at present to the grysbok than to the steenbok.

CHANGES IN SIZE THROUGH TIME

Figures 2 and 3 and Appendices 1 and 2 show that the various *Raphicerus* samples sometimes differ significantly in the mean lengths of molar and premolar rows (significance in this context means that the probability of a chance difference between two means is less than 0,05 as assessed by 'Student's t'). Particularly interesting are the statistically significant, larger mean dental row lengths observed in the Nelson Bay Robberg and Elands Bay (levels) 11–15 late Pleistocene samples. (The Nelson Bay Albany sample does not exhibit the same tendency towards larger specimen size, but the Albany Industry in fact extends into the early Holocene, and most of the measurable Nelson Bay Albany specimens are between *c.* 9 000 and 8 000 radiocarbon years old. The Elands Bay 11–15 specimens are all older than 9 600 radiocarbon years, while the Nelson Bay Robberg ones are all older than 14 000 years.) The Elands Bay 11–15 sample and especially the Nelson Bay Robberg one accumulated under very much cooler-than-present conditions (see Van Zinderen Bakker & Butzer 1973 for a general statement on late Pleistocene climates in southern Africa; Butzer 1973 for a specific statement on Nelson Bay). It is therefore tempting to hypothesize the operation of Bergmann's Rule in *Raphicerus*. (This 'Rule' states that, all other things equal, individuals belonging to a single mammalian species will tend to be larger in colder climates. This is because as an animal grows, its volume, which produces heat, increases more rapidly than its skin area, which dissipates it. Bergmann's Rule apparently operates on many extant mammal species with broad latitudinal distributions, and has been convincingly used to explain, for example, the relatively larger mean size of several species of small mammals in Last Glacial deposits in Pennsylvania. See Guilday 1971: 251–252.) One important difficulty in using Bergmann's Rule to explain the relatively long dental rows in the terminal Pleistocene *Raphicerus* samples from Nelson Bay and Elands Bay is that there are smaller, but still significant mean differences among other Cape Biotic Zone samples (for example, between the average molar row lengths in the Die Kelders I LSA *R, melanotis* and comparative *R. melanotis* samples) which it would be difficult to attribute to temperature on present evidence. Additionally, it remains to be shown that relatively small differences in dental row length, even though statistically significant, would be reflected in overall body size. In particular, it is possible that a slightly (but significantly) increased mean dental row length might occur in response to a change in vegetation (and diet), without any corresponding change in mean body size. It should be possible to gain some contol over this problem by measurements planned to be made soon on various post-cranial elements (which should reflect mean body size directly). If the material is available in museums, it would also be relevant to obtain measurements on *Raphicerus* specimens from present-day environments characterized by different mean annual temperatures.

POPULATION STRUCTURE

Figure 5 presents the minimum numbers of *Raphicerus* individuals in each of seven successive dental eruption/wear categories for each of the sites listed in Table 1 (excepting Duinefontein). The definitions of the eruption/wear states are given in the caption of the figure. Unfortunately, there are virtually no published data on the schedule (in months or years) of dental eruption and wear in *Raphicerus* spp. so that it is impossible to place chronological limits on the dental states in the figure. Since some of the dental states almost certainly have much broader chronological limits than others, it is therefore impossible to compute life tables or survivorship curves from the data in the figure (compare Kurtén 1953: 42ff.; Voorhies 1969: 24ff.; or Reher 1974: 117–122). The figure does show, however, that dentitions assignable to Category VII, in which the crowns of the teeth are worn down to near the level of the alveolus, are rare at all sites. This suggests that individuals of *Raphicerus* do not ordinarily survive into very old age, however that may be defined chronologically.

Data presented by Mentis (1972: 74–75) indicate that it is in dental state III (M2 erupting to erupted, but essentially unworn) that females of *Raphicerus* spp. become capable of bearing their first young. As a first step towards determining if there is meaningful patterning in the data presented in Figure 4, this fact has been used to regroup the data for each site into two broad subdivisions: (1) Categories I and II (with M2 unerupted and presumably including no sexually mature individuals) and (2) Categories III–VII (with M2 erupting to erupted and presumably including mostly sexually mature individuals).

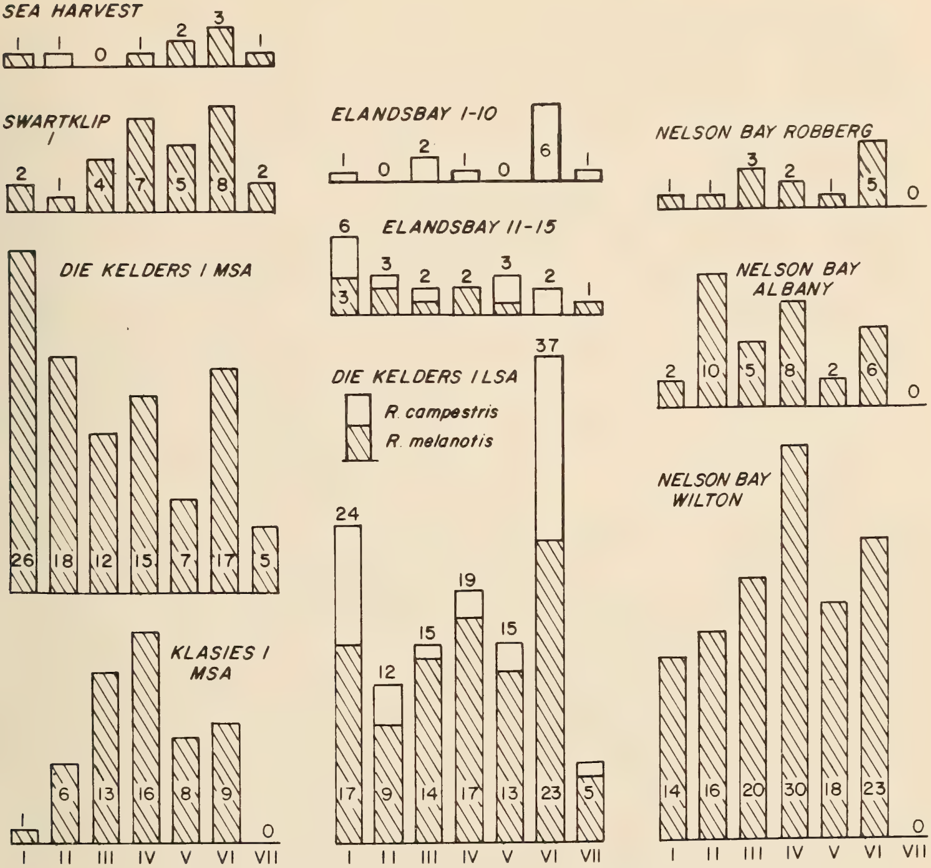


Fig. 5. Histograms showing the frequencies of *Raphicerus* individuals in different dental states in samples from the sites listed in Table 1 (excluding Duinefontein). The dental states are defined to include individuals in which (I) dP4 was erupting to erupted, but essentially unworn; (II) M1 was erupting to erupted, but essentially unworn; (III) M2 was erupting to erupted, but essentially unworn; (IV) M3 was erupting to erupted, but essentially unworn; (V) P4 was erupting to erupted, but essentially unworn; (VI) P4 was in early to mid wear; and (VII) P4 was in late wear.

The regrouped data are presented in Table 2. As the caption of Table 2 shows, application of the chi-square statistic to this data reveals several differences significant at the 0,05 level or below. The differences are very difficult to interpret, however, For example, among the archaeological sites, the two earlier Upper Pleistocene ones (with 'Middle Stone Age' materials)—Klasies I (MSA) and Die Kelders I (MSA)—display roughly the lowest and highest percentages of combined categories I and II, while the remaining sites—Elands Bay, Nelson Bay, and Die Kelders I (LSA) (all with 'Later Stone Age' materials) exhibit a wide range of intermediate values.

Table 2. Numbers of *Raphicerus* individuals in dental states I–II and III–VII in Cape Biotic Zone samples. (Based on data in Figure 5.)

DENTAL	ELANDS BAY		DIE KELDERS I		NELSON BAY CAVE			SWART-	SEA	KLASIES I
STATES	1–10	11–15	LSA	MSA	Wilton	Albany	Robberg	KLIP I	HARVEST	MSA
	A	B	C	D	E	F	G	H	I	J
I/II	4 (14%)	14 (37%)	50 (31%)	44 (44%)	30 (25%)	12 (35%)	2 (14%)	3 (10%)	2 (22%)	7 (13%)
	K	L	M	N	O	P	Q	R	S	T
III/VII	24 (86%)	23 (63%)	111 (69%)	56 (56%)	91 (75%)	21 (65%)	12 (85%)	26 (90%)	7 (78%)	46 (87%)
	28	37	161	100	121	34	14	29	9	53

DENTAL	DIE KELDERS I		ELANDS BAY	
STATES	*R. melanotis*	*R. campestris*	*R. melanotis*	*R. campestris*
	U	V	W	X
I/II	26 (27%)	10 (33%)	5 (50%)	5 (24%)
	Y	Z	A'	B'
III/VII	72 (73%)	20 (67%)	5 (50%)	16 (76%)
	98	30	10	21

Selected Chi-square values:

AB, KL = 3,32, p = 0,10–0,05
CD, MN = 3,91, p = 0,05–0,025
EF, OP = 1,21, p = 0,50–0,25
FG, PQ = 1,34, p = 0,25–0,10
DJ, NT = 13,42, p < 0,001
CE, MO = 1,02, p = 0,25
BF, LP = 0,00, p = 0,95–0,90
HJ, RT = 0,00, p = 0,95–0,90
DE, NO = 8,21, p < 0,001
DH, NR = 9,56, p < 0,001
FH, PR = 4,36, p = 0,05–0,025
EG, OQ = 0,28, p = 0,75–0,50
UV, YZ = 0,21, p = 0,75–0,50
WX, A'B' = 1,09, p = 0,50–0,25

It seems unlikely that the differences among sites in the proportions of combined categories I and II derive from differences among them in the relative frequencies of *R. melanotis* and *R. campestris* since differences in the proportion of I/II within *R. melanotis* and *R. campestris* at the two principal sites that contain both—Die Kelders I (LSA) and Elands Bay—are far from significant (Table 2). It is probable that no single factor is responsible, but rather that the differences in the age group proportions are brought about by multiple factors, for example, the precise nature of the vegetation near each site, the distance from the site at which animals were generally killed, the particular hunting and butchering methods used (in the case of archeological sites), whether the bones derive from animals that were killed or scavenged (in the case of the apparent carnivore accumulations at Swartklip and Sea Harvest), and so forth. One factor that is probably not involved is the season(s) at which the sites were occupied since both the grysbok and the steenbok apparently breed more or less continuously throughout the year, with only minor birth peaks, if any (Mentis 1972: 74–75; Smithers 1971: 221, 222). In this context, it is important to point out that the data in Figure 5 are presented in such a way that no discrete age clusters could be apparent, but in fact I observed no such clusters as I worked through the material.

Finally, in addition to age data, the nearly universal absence of horns in females of *Raphicerus* spp. makes it possible to obtain data on the proportions of the sexes in the various samples. Unfortunately, however, pre- and post-depositional factors leading to fragmentation of *Raphicerus* remains provide a clear source of bias in favour of the males since the hornless female skulls are far more fragile and are less likely to survive in pieces large enough to identify. In the Die Kelders I MSA sample, for example, in which fragmentation is especially pronounced, not a single identifiable female skull fragment was encountered, though males are represented by a minimum of 19 individuals. Even the male skulls have obviously suffered substantially from the extreme fragmentation, since the total of 19 individuals identifiable as to sex compares very poorly with the total of 81 animals (in dental categories IV–VII) which would have more or less full-sized horns, if they were males. Swartklip I reveals a similar, if not so extreme situation with 23 adult or near adult (category IV–VII) individuals identifiable on dental material, and only 11 on sexually relevant skull parts. All 11 are males. Here the author believes the explanation is predepositional—the Swartklip bone collector was probably a carnivore (Klein 1975*a*) whose jaws reduced the small hornless female skulls to pieces too small to identify (Swartklip contains virtually no identifiable braincase fragments of any bovid, except pieces with horncores attached). In any case, among all the samples, there is only one—the Die Kelders Later Stone Age assemblage —in which it seems likely to the author that pre- and post-depositional factors have not seriously biased sex ratios. Even here, the identifiable female skull fragments are generally not adequate for species identification, forcing the author to present a sex ratio for *R. melanotis* and *R. campestris* lumped: males–41, females–50. This does not differ significantly from 1 : 1 (binomial probability of a difference from parity roughly 0,25). Although there is some disagreement on the sex ratio in free-ranging *Raphicerus* spp. (Kerr & Wilson 1967; Wilson & Kerr 1969; Rowe-Rowe 1971; Penzhorn 1971), an overview of the data (Mentis 1972: 75–76), in combination with theoretical considerations on the population structure of small, non-gregarious, territorial antelopes, suggests a sex ratio of roughly 1 : 1 in living populations (Jarman 1974: 261).

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Appendix 1

Arithmetic mean (x̄), standard deviation (s), and sample size (N) for dental row and diastema lengths in the various *Raphicerus* samples considered in the text. (MM = males, FF = females, MMFF = males and females; DK 1 = Die Kelders 1; EBC = Elands Bay Cave; NBC W, A, R = Nelson Bay Cave Wilton, Albany, and Robberg; ZW 1 = Swartklip 1; KRM 1 = Klasies River Mouth 1; EFT = Elandsfontein.) All measurements are in millimetres.

dP_2–dP_4

Raphicerus melanotis

	Comparative										
	MM	FF	MMFF	DK 1 LSA	EBC 1–10	EBC 11–15	NBC W	NBC A	NBC R	ZW 1	KRM 1 MSA
x̄	20,40	20,99	20,90	21,41	—	20,80	20,96	21,75	22,20	20,80	—
s	—	0,790	0,767	0,819	—	—	0,769	1,060	—	—	—
N	1	9	10	49	—	1	13	2	1	1	—

Raphicerus campestris

	Comparative						*Raphicerus* sp.
	MM	FF	MMFF	DK 1 LSA	EBC 1–10	EBC 11–15	EFT
x̄	—	19,77	19,77	20,50	20,80	20,80	24,05
s	—	0,996	0,996	0,070	1,153	—	1,060
N	—	7	7	2	3	1	2

dP^2–dP^4

Raphicerus melanotis

	Comparative							
	MM	FF	MMFF	NBC W	NBC A	NBC R	ZW 1	KRM 1 MSA
x̄	21,50	21,98	21,93	22,05	21,78	23,00	22,85	—
s	—	0,944	0,903	0,908	0,377	—	1,401	—
N	1	9	10	13	4	1	4	—

Raphicerus campestris

	Comparative			*Raphicerus* sp.
	MM	FF	MMFF	EFT
x̄	20,70	21,30	21,23	25,20
s	—	1,366	1,290	—
N	1	8	9	1

P_2–P_4

Raphicerus melanotis

	Comparative										
	MM	FF	MMFF	DK 1 LSA	EBC 1–10	EBC 11–15	NBC W	NBC A	NBC R	ZW 1	KRM 1 MSA
x̄	20,00	19,03	19,51	19,15	—	—	19,23	—	22,00	19,10	20,10
s	0,906	0,275	0,810	1,380	—	—	0,570	—	—	0,826	—
N	4	4	8	13	—	—	3	—	1	12	1

Appendix 1 (*cont.*)

Raphicerus campestris

	Comparative			DK 1	EBC	EBC	*Raphicerus* sp. EFT
	MM	FF	MMFF	LSA	1–10	11–15	
x̄	17,15	17,63	17,60	17,45	18,40	—	22,27
s	0,636	0,757	0,670	0,923	—	—	1,021
N	2	3	5	4	1	—	3

$P^2 - P^4$

Raphicerus melanotis

	Comparative			NBC	NBC	NBC	ZW 1	KRM 1
	MM	FF	MMFF	W	A	R		MSA
x̄	20,38	20,03	20,20	18,00	20,90	19,00	20,87	—
s	1,034	0,499	0,775	—	0,141	1,838	0,997	—
N	4	4	8	1	2	2	6	—

Raphicerus campestris

	Comparative			*Raphicerus* sp.
	MM	FF	MMFF	EFT
x̄	19,26	20,30	19,70	23,60
s	0,928	0,211	1,631	—
N	5	5	10	1

$M_1 - M_3$

Raphicerus melanotis

	Comparative			DK 1	EBC	EBC	NBC	NBC	NBC	ZW 1	KRM 1
	MM	FF	MMFF	LSA	1–10	11–15	W	A	R		MSA
x̄	29,75	28,98	29,36	30,67	30,30	32,30	29,96	30,66	31,60	29,78	29,76
s	0,794	0,838	0,862	1,270	—	—	0,858	2,079	—	51,00	1,001
N	4	4	8	77	1	1	32	3	2	25	8

Raphicerus campestris

	Comparative			DK 1	EBC	EBC	*Raphicerus* sp.
	MM	FF	MMFF	LSA	1–10	11–15	EFT
x̄	30,43	29,42	29,82	30,27	30,13	31,70	33,00
s	0,227	0,141	1,177	1,792	1,341	0,014	1,607
N	4	6	10	13	6	2	37

Appendix 1 (*cont.*)

M^1-M^3

	Raphicerus melanotis Comparative MM	FF	MMFF	NBC W	NBC A	NBC R	ZW 1	KRM 1 MSA
x̄	25,69	25,78	25,73	26,39	25,71	26,86	26,73	25,17
s	0,581	0,942	0,714	0,916	0,785	0,537	0,780	0,306
N	7	5	12	30	8	5	17	3

	Raphicerus campestris Comparative MM	FF	MMFF	*Raphicerus* sp. EFT
x̄	26,37	26,56	26,44	29,01
s	1,401	1,363	1,349	0,870
N	11	7	18	9

Diastema

	Raphicerus melanotis Comparative	DK 1 LSA	EBC	*Raphicerus campestris* Comparative	DK 1 LSA	EBC
x̄	19,08	19,57	20,85	23,60	24,42	23,05
s	1,425	1,764	1,909	0,927	1,220	2,799
N	8	19	2	4	10	6

P_2-P_4/M_1-M_3

	Raphicerus melanotis Comparative MM	FF	MMFF	*R. campestris* Comparative MM	FF	MMFF
x̄	0,675	0,657	0,666	0,567	0,615	0,596
s	0,037	0,022	0,030	0,023	0,014	0,031
N	2	3	5	4	4	8

P^2-P^4/M^1-M^3

	Raphicerus melanotis Comparative MM	FF	MMFF	*R. campestris* Comparative MM	FF	MMFF
x̄	0,811	0,766	0,783	0,736	0,731	0,734
s	0,039	0,033	0,040	0,027	0,011	0,021
N	3	5	8	5	3	8

Appendix 2

List of samples of *Raphicerus melanotis* and *R. campestris* between which statistically significant mean differences in dental row or diastema length may be demonstrated. 't' = value of Student's t; df = degrees of freedom; p = significance level (taken as significant if $\leq$ 0,05) [R. m. = *Raphicerus melanotis* (comparative unless otherwise indicated); R. c. = *R. campestris* (comparative unless otherwise indicated); NBC W, A, R = Nelson Bay Cave Wilton, Albany and Robberg; EBC = Elands Bay Cave; ZW 1 = Swartklip 1; DK 1 = Die Kelders 1; KRM 1 = Klasies River Mouth Cave 1).

	t	*df*	*p*
dP_2-dP_4			
R. m. > R. c.	2,55	15	0,05–0,02
P_2-P_4			
R. m. > R. c.	4,61	11	< 0,001
NBC R R. m. > R. m.	2,76	7	0,05–0,02
NBC R R. m. > ZW 1 R. m.	3,23	11	0,01–0,001
P^2-P^4			
ZW 1 R. m. > NBC W R. m.	2,52	7	0,05–0,02
M_1-M_3			
EBC 11–15 R. m. > NBC W R. m.	2,64	31	0,02–0,01
NBC R R. m. > R. m.	3,34	8	0,02–0,01
NBC R R. m. > NBC W R. m.	2,68	32	0,02–0,01
NBC R R. m. > KRM 1 MSA R. m.	2,36	8	0,05–0,02
DK 1 LSA R. m. > NBC W R. m.	2,88	107	0,01–0,001
DK 1 LSA R. m. > ZW 1 R. m.	2,88	100	0,01–0,001
DK 1 LSA R. m. > KRM 1 MSA R. m.	2,06	83	0,05–0,02
DK 1 LSA R. m. > R. m.	2,82	83	0,01–0,001
EBC 11–15 R. c. > R. c.	3,49	8	0,02–0,01
M^1-M^3			
NBC W R. m. > R. m.	2,35	40	0,05–0,02
NBC W R. m. > KRM 1 MSA R. m.	2,30	31	0,05–0,02
NBC R R. m. > R. m.	3,13	15	0,01–0,001
NBC R R. m. > NBC A R. m.	2,73	11	0,05–0,02
NBC R R. m. > KRM 1 MSA R. m.	3,09	23	0,01–0,001
ZW 1 R. m. > NBC A R. m.	3,09	18	0,01–0,001
ZW 1 R. m. > KRM 1 MSA R. m.	3,39	18	0,01–0,001
ZW 1 R. m. > R. m.	3,84	27	< 0,001
P_2-P_4/M_1-M_3			
R. m. > R. c.	2,86	9	0,02–0,01
R. m. > R. c.	4,03	11	0,01–0,001
Diastema			
R. c. > R. m.	5,30	10	< 0,001
DK 1 R. c. > DK 1 R. m.	8,03	27	< 0,001

PRELIMINARY PALYNOLOGICAL RESULTS FROM THE ALEXANDERSFONTEIN BASIN NEAR KIMBERLEY

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(With 3 figures)

ABSTRACT

An extensive sampling programme for pollen analysis was carried out around Kimberley, Republic of South Africa, as part of the multi-disciplinary Alexandersfontein Project. Preliminary results from late to middle Holocene spring and alluvial deposits at Uitzigt, in the Alexandersfontein Basin, suggest a wetter environment during deposition of part of the spring sediments, and conditions not unlike the present for the alluvial deposits.

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INTRODUCTION

Pleistocene lake deposits in the Alexandersfontein Basin near Kimberley, were first described by Butzer *et al.* (1973) and Van Zinderen Bakker & Butzer (1973). In order to study this region in terms of its environmental history and prehistoric ecology, a multi-disciplinary programme, the Alexandersfontein Project, was undertaken in 1974 under the direction of K. W. Butzer of the University of Chicago. A complex succession of mid-Pleistocene to Holocene lakes, with related spring deposits, was identified and archaeological surveying, mapping, collecting, testing and excavating was initiated. In order to assist in developing a model of prehistoric settlement patterning related to spring and shoreline micro-habitats in time and space, a sampling programme for chronometric dating and palynological study was also undertaken. The isotopic studies, by R. Stuckenrath of the Smithsonian Institution, are still in progress, and no final chronometric dates for the pollen profiles are reported here. The palynological investigations were carried out at the Institute for Environmental Sciences at the University of the Orange Free State, under the supervision of E. M. van Zinderen Bakker Sr. The slides were mounted in glycerine jelly and are kept in the slide collections of the Institute and identifications were made by means of the pollen reference collection, built up by Van Zinderen Bakker.

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THE SAMPLING PROGRAMME

A total of 87 samples was collected for pollen analyses from the Alexandersfontein area. These cover the stratigraphic and lithologic range of sediments at the fossil spring sites Uitzigt, Mauritsfontein and Benfontein. Good pollen yield was limited to organic spring deposits at Uitzigt and a closely linked alluvial terrace a little downstream; these units have been dated by C^{14} as late Holocene, i.e. within the last 5 000 years. Pollen diagrams of these two sites are presented in this paper. Exploratory samples from this area also demonstrated an absence of pollen from weathered Karoo shale exposures, mid-Pleistocene lake chalks and Upper Pleistocene spring marls. Poor, but in some cases suitable, pollen or spores were recovered from Upper Pleistocene spring chalks, underlying the organic spring deposits at Uitzigt (sample no. 5884), and from the B-horizon of the paleosol developed in late Pleistocene littoral deposits at the Mauritsfontein site (5689, 5690 and 5762). Pollen analyses of the samples are in progress.

In order to obtain a better understanding of the fossil pollen assemblages of the whole region (see Fig. 1), 35 additional samples were taken from the late Holocene spring mucks and lake marls at the rock-engraving site complex of Klipfontein (60 km west of Kimberley), from Holocene alluvia on the Vaal

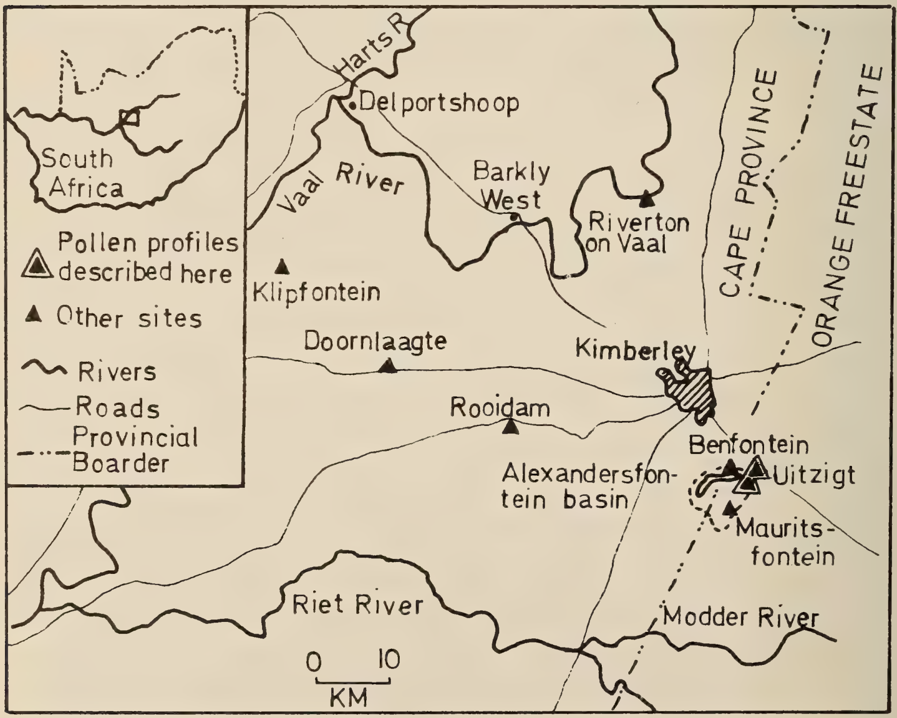

Fig. 1. Alexandersfontein in its regional setting.

River, and from mid-Pleistocene, freshwater limestones at Doornlaagte and Rooidam (± 50 km west of Kimberley). Pollen was found in most of these, with the exception of those from Rooidam, and analyses on them are in progress.

VEGETATION AT UITZIGT

During December 1974, a survey of the modern vegetation around the Uitzigt spring was carried out for comparison with data on the present pollen rain and fossil spectra. The site lies near the north-eastern margin of the treeless 60 km^2 Alexandersfontein Basin. The regional vegetation is Kalahari Thornveld invaded by Karoo and around Kimberley this veld type consists of *Acacia giraffae*-savannah with grasses of the Dry Cymbopogon–Themeda veld and some of those of the Bankenveld (Acocks 1953). The spring site is surrounded by an isolated group of trees comprising the following species: *Diospyros lycioides*, *Rhus pyroides*, *Ziziphus mucronata*, *Asparagus laricinus* and *Lycium* sp., while the near-by savannah is composed mainly of *Acacia giraffae*, *A. karoo*, *A. tortilis*, *Ziziphus mucronata*, *Ehretia rigida* and *Lycium* sp. In the veld around the spring many species of Gramineae occur, e.g. *Eragrostis* spp., *Cynodon dactylon*, *Sporobolus tenellus* etc., and Compositae like *Pentzia* spp., *Gazania* sp., and *Gnaphalium* sp., as well as other herbs such as *Lasiosiphon* sp., *Thesium hystrix*, *Stachys* sp., *Salvia* sp., *Portulaca* sp., *Walafrida densiflora*, *Sutera* sp., *Limosella capensis*, *Alectra orobanchoides*, *Psilocaulon* sp., *Hypertelis* sp., *Limeum aethiopicum*, *Asclepias* sp., *Cordylogyne* sp., *Convolvulus* sp., *Salsola* sp., *Polygala* sp., *Indigofera alternans*, *Zygophyllum* sp., *Apium graveolens*, *Umbellifera centella*, *Amsinckia* sp., *Datura* sp., *Lycium* sp., *Albuca* sp., *Trachyandra* sp., etc. Cyperaceae occur in moist patches around the spring.

POLLEN DIAGRAMS FROM UITZIGT

THE SPRING-EYE DEPOSITS

Samples were removed from the calcareous organic spring-eye deposits at Uitzigt, which are resting on calcrete, by means of a Hiller auger (sample nos. 5677–82 and 5715–39), as well as a surface sample for the assessment of the modern pollen rain. All samples proved to contain countable pollen. Detailed pollen analyses were performed on four samples from the profile (1974, cores 3, 4) and also on the surface sample. The species composition (see Fig. 2) was calculated by examination of 250, or in a few cases 100, pollen grains, depending on the yield of the sample. Cyperaceae, Chenopodiaceae, Gramineae, Compositae, Aizoaceae, *Diospyros* and *Rhus* are the main pollen components. The oldest sample shows an increase in percentage of Cyperaceae which are probably related to spring activity and a decrease in pollen of the isolated group of trees now found growing round the spring (*Diospyros* and *Rhus*). The surface sample from the eye shows a sharp increase in the percentage of grasses, probably a result of the high precipitation during the previous

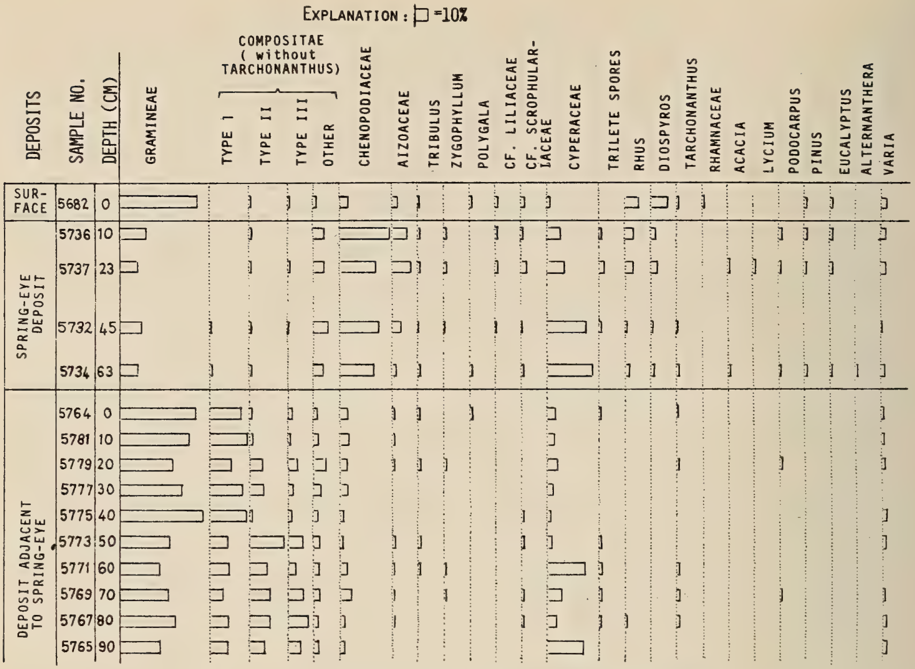

Fig. 2. Pollen diagram of the spring deposits at Uitzigt.

season. There is also a higher percentage of *Diospyros* and *Rhus* in this sample. The presence of rare pollen of the introduced plants, *Pinus*, *Eucalyptus* and *Alternanthera*, as well as the presence of a seed of *Datura*, a naturalized plant, at 11 cm, suggests that the deposits are disturbed to some extent.

DEPOSITS ADJACENT TO THE SPRING-EYE

Further samples from a different generation of calcareous organic spring sediment were collected from a pit (1975, no. 1) about 5 metres from the eye and situated about 1 metre higher on the slope. The material is similar in appearance to those from the eye, but are more consolidated and undisturbed. The deposits have a thickness of about 90 cm. A few *in situ* artefacts and pieces of ostrich eggshell are present. The pollen of ten samples, which are not as rich as the eye-deposits, suggests wetter conditions for these deposits than those from the eye, for the following reasons (see Fig. 2):

1. They show a marked reduction in the percentage of pollen from the halophytic Chenopodiaceae.

2. They show a reduction in the percentage of Aizoaceae pollen, which is taken to represent a karoid type of vegetation. It is believed that this group of pollen grains may also include some specimens from the closely related Phytolaccaceae and Portulacaceae families.

3. There is an increase in the percentage of Gramineae (between 30 and

64%), as the highest percentage obtained in the spring-eye samples was 19,2 per cent. The former values compare favourably with the surface sample (59,6%), which as noted possibly reflects a very wet year.

Although the Compositae are also more abundant in these deposits, it is believed that the grass : Compositae ratio used by Van Zinderen Bakker (1957) and Coetzee (1967) to measure dryness is not applicable here, because the Compositae present are not the usual types for this area. There are few of the normal spiny forms which make up the majority of Karoo and South African species and which were found in the spring-eye deposits. Compositae types II (Stoebe-like morphology) and III (Artemisia-like morphology) probably form part of the spring vegetation, firstly because they show the same distribution as the Cyperaceae, which are probably related to spring activity, and, secondly, because these types are often found together in clusters, showing that they do not represent the pollen rain, but probably grew on the site. These forms therefore cannot suggest dryness of the surrounding veld. On the other hand, the pollen of Compositae type I (Lactuca-like morphology) which is absent in the surface and younger samples of the eye, is probably blown in from the surrounding veld because it shows a similar distribution as the Gramineae which mainly represent the veld. The samples contain very few tree pollen grains. *Rhus* is only rarely recorded at 80 cm, while *Tarchonanthus* and winged pollen grains of *Podocarpus* which could have been transported for hundreds of kilometres by the wind, are found in small numbers throughout the profile. In contrast to the present situation the pollen spectra suggest the absence of trees growing directly around the spring at the time of deposition.

THE ALLUVIAL TERRACE NEAR UITZIGT

During early February 1975, a series of samples (nos. 5799–5816) was collected from the side of a gully in an alluvial terrace of Holocene age near Uitzigt. The gully is situated about 100 metres from the spring at a lower altitude in the Alexandersfontein Basin. The terrace is composed of grey organic calcareous deposits with calcrete pebbles. Three samples were analysed from depths of 10, 60 and 110 cm in the wall of the gully as well as a surface sample. The terrace sediments, which naturally represent a much drier environment than the spring, show a very high percentage (> 60%) of Chenopodiaceae, with smaller numbers of Compositae, grasses and trilete spores (Pteridophyta and ?Bryophyta) (see Fig. 3). The pollen spectra at the three levels are similar to the surface sample from the gully except in the higher percentage of grasses, and correspondingly lower percentage of Chenopodiaceae in the latter sample. As in the surface sample from the spring-eye, this is likely to result from the unusually high precipitation of the last two years. The drier environment as suggested by the pollen spectra from the terrace is therefore probably not much different from the average conditions of recent times. Unlike the spring deposits adjacent to the eye, the Compositae types in the alluvial terrace were the same as those in the surface samples and spectra from the spring-eye.

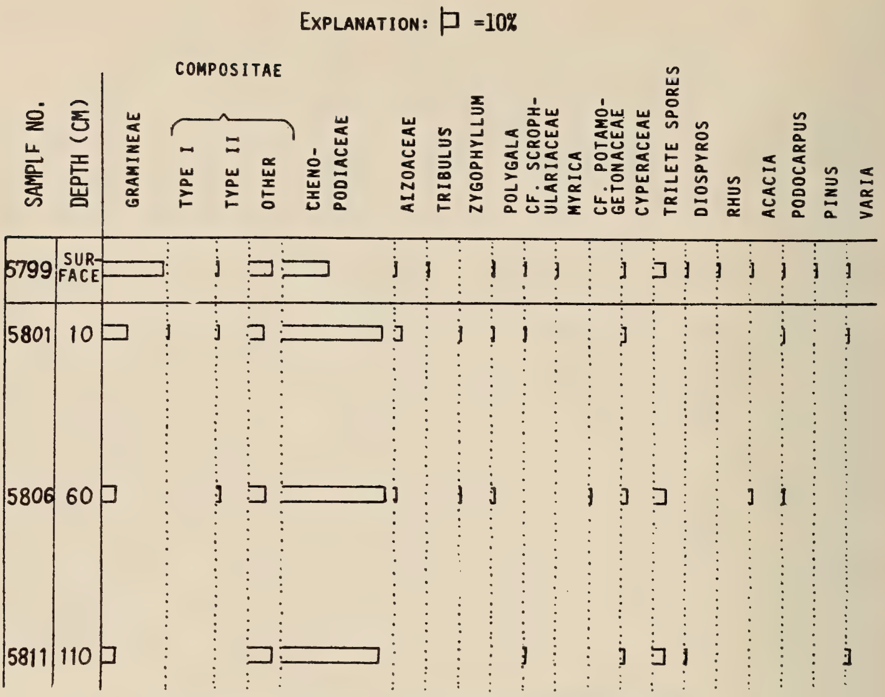

Fig. 3. Pollen diagram of the alluvial terrace near Uitzigt.

CONCLUSION

As was expected, the palynological work in the northern Cape region produced better pollen assemblages from the younger organic spring deposits and alluvial terraces than from the lake chalks and calcretes. However, sporomorphae obtained from deposits of the latter kind at Doornlaagte, Klipfontein and Uitzigt show that these deposits are not entirely devoid of potential for palynology. When comparing the three pollen profiles of the organic spring and alluvial deposits from the Alexandersfontein Basin, as described here, the spectra from the deposits adjacent to the spring-eye differ considerably from the assemblages of the spring-eye deposits and the alluvial terrace, which show greater similarity to assemblages of present pollen rain as obtained from the surface samples. The former appear to represent a more humid environment. The final interpretation of these results can best be made when the isotopic and sedimentological studies are completed and the remaining pollen results available.

ACKNOWLEDGEMENTS

I wish to express my thanks to Professor K. W. Butzer for initiating this research project and for his encouragement and suggestions. Professor E. M. van Zinderen Bakker Sr of the Institute for Environmental Sciences supervised the project and kindly supported the fieldwork. I am also grateful to Mr D. B. Müller and Dr H. J. T. Venter for assisting me with the identification of plants and to Mr C. E. Boshoff and Professor A. Horowitz for their assistance with the sampling.

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SECTION 4

ARCHAEOLOGY

ANALOGY AND ARCHAEOLOGY

By

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Analogy, the relationship of things to their models, is the lifeblood of the historical sciences. Archaeology, as one of the historical sciences, would not exist without analogy. We can know about the prehistoric past only in terms of analogy with models taken from the present. It is extraordinary, therefore, to observe that intensive systematic teaching in the philosophical mechanisms of analogy is neglected in our schools of prehistory; few of our teachers of prehistory are able to present a theoretical account of analogy and its practical application in archaeology. (Sapire 1972.)

The practical implications of analogy for the research archaeologist are very clear. Each and every research archaeologist should have his own personal logbook of analogies and models for every aspect of his work from his reconstruction of prehistoric technological behaviour to the analysis of geological processes responsible for the mass deposition agencies preserving his site. Knowing archaeologists as I do, they may accept this exhortation, but do little about it. It is sad to observe the Palaeolithic or Stone Age archaeologist who has never lived with living representatives of his specialized knowledge, hunter–gatherers who have managed to survive into the latter twentieth century. Examples of ivory-tower prehistorians, entirely lacking in personal experience of hunter–gatherers or other living peoples related to archaeology, are only too common. An engineer specialized in the fabrication of metals need not do the work himself, but he keeps close to it in the work of his factory managers; archaeologists do not have factory managers, so they should be obliged to do the dirty work for themselves and get in on the hunter–gatherer scene personally.

What essentially practical science has the richest store of models for the 1975 field archaeologist? In my opinion the science of mineral exploration is a prime source of models for modern archaeology. Both archaeology and mineral exploration search for obscure materials located as minute fractions in vast bodies of enclosing but sterile deposit.

The science of mineral exploration combines three sister sciences: exploration geophysics, exploration geochemistry and exploration geology.

Somehow or other the archaeologist has got to get the practical help of scientists in all three exploration disciplines. Of course, for many years archaeologists have recognized the relevance of some exploration techniques to their subject, but no full-scale attempt to use mineral exploration techniques for archaeological purposes has ever been made.

To quote a single example: in 1959 Dr Tony Brink and I were able to use a 30 inch (76 cm) boring machine to drill a line of seven holes in the Chuniespoort Valley slope deposits, some up to 12 metres deep. We were able to probe the

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Ann. S. Afr. Mus. **71**, 1976: 201–202.

Chuniespoort soils in our search for archaeological data. Alas, we were not able to expand our 1959 experiment to other sites, but substantial areas of South African landscape cry out for the 1959 Chuniespoort treatment.

If we were able to acquire mineral exploration teams to help in fieldwork we might be able to locate entirely new sources of archaeological data. The history of South African mineral exploration at once suggests a valuable model for the location of new archaeological deposits. South Africa's new frontier in mineral exploration lies along the south bank of the Orange River in the northern Cape. Here we have a region known as Bushmanland which was ignored as a potential source of base minerals because it was a granite region and granites were not recognized as a source of base minerals. However, things have changed. Exploration geophysics, geochemistry and geology have now discovered the history of granite development revealing that base metal ore bodies exist in the earliest pre-granite rocks subsequently formed into granites and gneisses. Vast wealth awaits the mineral exploration team capable of locating the right kind of pre-granite rocks in a granite assemblage.

A new wealth of archaeological information relating to man or environment may await the archaeologist if we search new deposits with geophysical, geochemical and geological techniques borrowed from mineral exploration sciences. The traditional sources of our data are caves and slow-fill areas: what about all other forms of superficial deposit? The evidence we want may be present only in geological or geochemical form, but it may surprise us all.

Finally, I should like to remark that the pace of archaeological research is too slow. For example, the slow and painful reassessment of European Cenozoic environments now taking place could have been completed in a fraction of the time by a single mineral exploration company. The same comment applies to the unduly prolonged exploration of some archaeological sites.

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THE HOLOCENE AND UPPER PLEISTOCENE SEQUENCE IN THE SOUTHERN CAPE

By

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(With 3 figures)

ABSTRACT

In 1971 a research project aimed at the study of the late Quaternary environment and culture change in the southern Cape region was initiated and observations have been made at several archaeological sites. The most promising is Boomplaas Cave where some five metres of deposits range in age from Holocene to early Upper Pleistocene. The well-stratified sequence includes cultural material as well as plant and animal remains. Most recently the cave was used by prehistoric herders, ancestral Hottentots, as a stock-kraal and prior to that the cave was used by hunters and gatherers as a locality for the storage of *Pappea capensis* fruits. Occupation levels of the earlier Holocene and Upper Pleistocene are still under study. The larger mammalian faunal remains show shifts from closed to more open and back to closed habitat species through the whole sequence that may reflect major trends in the pattern of environmental change. Confirmation of this patterning is being sought in the current study of the rich microfaunal samples accumulated from owl pellets and unrelated to human activities. The major industrial change in the sequence is prior to 21 000 years B.P. and while this does not directly correlate with environmental change, there are lower order technological changes which may reflect adaptive responses to changing environment in the late Upper Pleistocene and Holocene.

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INTRODUCTION

The Southern Cape which is defined here as equivalent to the eastern zone of the Cape Folded Mountain Belt (Wellington 1955: 108) comprises a series of east–west trending mountain ranges and a narrow coastal plain. It has been described as part of the Cape biotic zone (Hendey 1974: 16) and is part of the landscape of the Cape Flora, the 'fynbos'. A major ecological boundary separates the Southern Cape from the more arid Karoo of the immediate interior of South Africa and the boundary lies along the inland margin of the fold mountains. In 1971 a research project, 'The Langkloof Archaeological Research Project: Late Quarternary environment and culture change in the Southern Cape' was initiated at the University of Stellenbosch. This is conceived as primarily an archaeological study with a focus on tracing changing human adaptations in the Upper Pleistocene and Holocene. Because the study of

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adaptation is the study of goodness of fit between human behaviour and the total environmental context in which it operates, the research project is of necessity multi-disciplinary and indeed archaeological fieldwork where undertaken on an adequate scale and with due attention to research design can yield basic data that contribute directly to palaeoecological and palaeoclimatic studies.

The southern Cape is archaeologically one of the more intensively studied regions of southern Africa and, in the main, cave occurrences along the coast have attracted attention. Much of the work has, however, been done outside of reference to any specific design and has been in this sense opportunistic, but it has shown the establishment and continuation of stable densities of human populations in the region through the last hundred thousand years. That Upper Pleistocene and Holocene settlement patterns included the occupation of caves allows sampling to be directed at this type of occurrence with some advantages in preservation of materials and their context. A bias in previous studies in the southern Cape lies not so much in the emphasis on cave excavation as in the selection of cave sites mainly in the coastal zone. At coastal caves there is the maximum effect of wide-ranging changes due to eustatic lowering of sea-level during the Upper Pleistocene which are difficult to factor out from more direct effects of changes in climate, flora and fauna on past human habitats. The goal of the Langkloof archaeological project has been to build on and extend previous observations on culture change and changes in past environment.

PROJECT PROGRESS

The initial observations were made in the Langkloof and were to follow up on preliminary excavations undertaken by Jolly in 1969. Of several sites sampled by Jolly only Rautenbach's Cave (33.31S, 23.42E, 1 : 50 000 sheet reference 3323 DA Voorkloof) would seem to warrant further investigation. It occupies a small anticlinal structure in Witteberg quartzite perched on a hillside in the entrance to a small kloof draining into the Baviaans River. The floor is 12 metres by 6 metres and the deposit is some 2 metres deep in Jolly's cutting. The upper metre of deposit is a grey ashy unit with some preserved organic remains. Surface disturbances made by rodents and the cutting in this upper unit show the occurrence of pottery, *Themeda triandra* grass bases, *Boophone disticha* bulbar leaves, *Pappea capensis* fruits and *Freezia* sp. corm scales. The middle unit of the deposit is a red-brown loam with spall material and oxidation here precludes organic preservation. The basal part of the deposit from 15 cm above bedrock is a black spall-free iron humate stained horizon. The upper unit is Holocene in age and it is evident on the typology of cultural material included in the lower units that the sequence extends into the Upper Pleistocene. A single radiocarbon determination gave a result of 12 560 ± 100 (Pta. —251) apparently related to the lower portion of the sequence. The precise

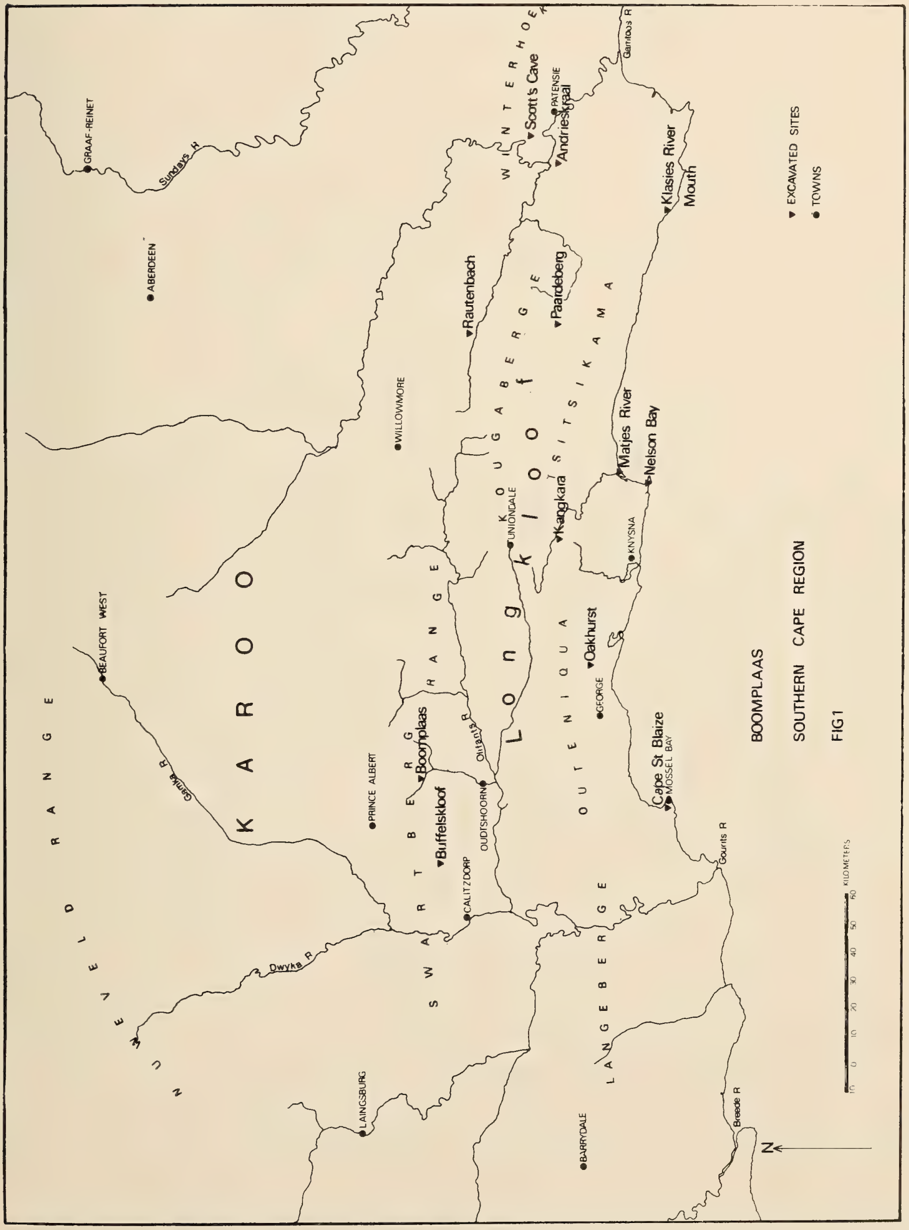

Fig. 1. Map of the southern Cape showing the location of Boomplaas Cave in relation to other important excavated cave sites.

provenance of the sample submitted by Jolly is unknown. Rautenbach's Cave draws attention to the possibility of extending observations on the subsistence ecology of Holocene hunter–gatherers made for example in the far eastern limit of the Cape Folded Belt at Melkhoutboom Cave (Deacon H. J. 1972). The same potential, however, exists at other sites in the Langkloof. The cultural materials from the Upper Pleistocene units are of some typological interest as they include blades within the size range of the Howieson's Poort industry. Jolly's samples, however, are inadequate for any detailed study.

In excavations carried out in 1972 by H. J. Deacon and R. G. Klein in collaboration with J. Deacon, M. Brooker and with the assistance of students from the University of Stellenbosch, two cave sites in the Langkloof were test excavated. The Kangkara Cave (33.47S, 23.05E, sheet 3323 CC Kruisvallei) is an open rock shelter cave in Table Mountain sandstone in the Upper Keurbooms River valley. Excavation here showed 2 metres depth of deposit without reaching bed-rock. The lowest 30 cm of the sequence sampled is an iron humate stained unit that includes faceted platformed flakes, prepared cores and pre-eminent selection of quartzite raw materials. This would appear to relate to the early Upper Pleistocene and correlates with the basal units at caves on the adjacent coast. A disconformity marked by a rock tumble separates the earlier culture-stratigraphic unit from the overlying terminal Pleistocene and Holocene sequence. The latter covers more than 12 500 years (Pta.-782) and artefactual as well as organic remains (bone and shell) are preserved. Within the culture-stratigraphic terminology in use in the eastern zone of the Cape Folded Belt, the rock tumble and overlying layers include materials related to the Robberg, Albany and Wilton industries.

The second test excavated site was Paardeberg Cave in the Kougaberge, north of Joubertina (33.44S, 24.01E, sheet 3324 CA Sandvlakte). This is a large cave which in spite of its remoteness had suffered some disturbance by casual digging in 1966. Although there is an estimated thickness of 1 metre of later Holocene deposit in a part of the cave, the test excavation was located towards the mouth where the deposits are thinner to establish the sequence and preservation in pre-Holocene levels. The sequence intersected was 80 cm deep and overlying an oxidized stony yellow-brown loam layer (10 cm) containing a few large quartzite flakes was a unit less oxidized and of greyer hue that showed a high density of silcrete artefacts. Typologically the industry is of some interest as it includes unifacial and bifacial points and 'nosed' scrapers associated with a strong blade element. The top of this unit is dated to greater than 44 000 years (Pta.-773). A disconformity separates the above unit from cultural material and organic remains of Holocene age. The Holocene remains are of interest as at Rautenbach's Cave through the good condition of preservation of plant and bone remains. These initial investigations within the project showed that there were a number of cave sites within the mountain zone with sequence extending into the Upper Pleistocene. They also pointed to the problem of obtaining observations on associated organic remains for much of the Upper

Pleistocene in areas underlain by the acid rocks of the Cape System. A further aspect made more prominent by these observations was the discontinuities in the sequences exposed. At these sites inland and again at sites on the coast it appeared that the time range between some 40 000 and 15 000 years B.P. was not represented by any marked build up in deposits through occupation. Partial explanation for this may lie in eustatic changes in sea-level and settlement taking place on the now submerged coastal plain beyond the reach of investigators.

Further progress has depended on overcoming some of the limitations of the sites initially investigated. Following on Goodwin's (1930: 565) results from a 1930 excavation in the Cango Caves, a conscious search was made for sites in the Cango Beds, an upfaulted block of pre-Cape rocks that includes bands of limestone that would be more favourable for bone preservation. In the more durable sandstone–quartzite caves and shelters the build-up of deposits is slow, giving minimal separation of culture-stratigraphic units and making for maximal physical fragmentation of organic remains such as bone through simple trampling. The limestone area offered the prospect of giving a more expanded sequence. As the Cango Caves themselves serve as a tourist facility there are some added problems of excavation there and Boomplaas Cave 4 kilometres away was chosen for excavation. Subsequent work within the project which has amounted to some four months' excavation time during three separate field seasons has been concentrated on this site. As a long-sequence site, covering perhaps the last 80 000 years with human occupation throughout and reasonable preservation of associated faunal materials, Boomplaas Cave offers the potential of providing an excellent record of changing human adaptation in the southern Cape in the Upper Pleistocene and Holocene. While this investigation has become central to the Langkloof project in terms of the capabilities of the research team from Stellenbosch, another site, a large rock shelter cave on the farm Buffelskloof 15 km from Calitzdorp and some 30 km from Boomplaas, is currently being excavated by H. Opperman of the University of Fort Hare.

BOOMPLAAS CAVE

Boomplaas Cave occupies part of a fissure system in Drupkelderkop (33.23S, 22.11E, sheet 3322 AC Kangogrotte) opening above the floor of the valley at the same elevation as the Cango Caves. The opening to the fissure forming the cave has a floor area of some 250 metres. Thus far some 100 square metres have been excavated to a depth of approximately 1 metre and a sounding of 1 square metre (square P12) excavated to bed-rock. The latter has provided a section through the complete sequence. The deposits are some 5 metres thick and well stratified with discrete depositional units representing occupation and non-occupation horizons. A suite of seven radiocarbon age determinations currently gives a time scale for the sequence, the lower half of which is older

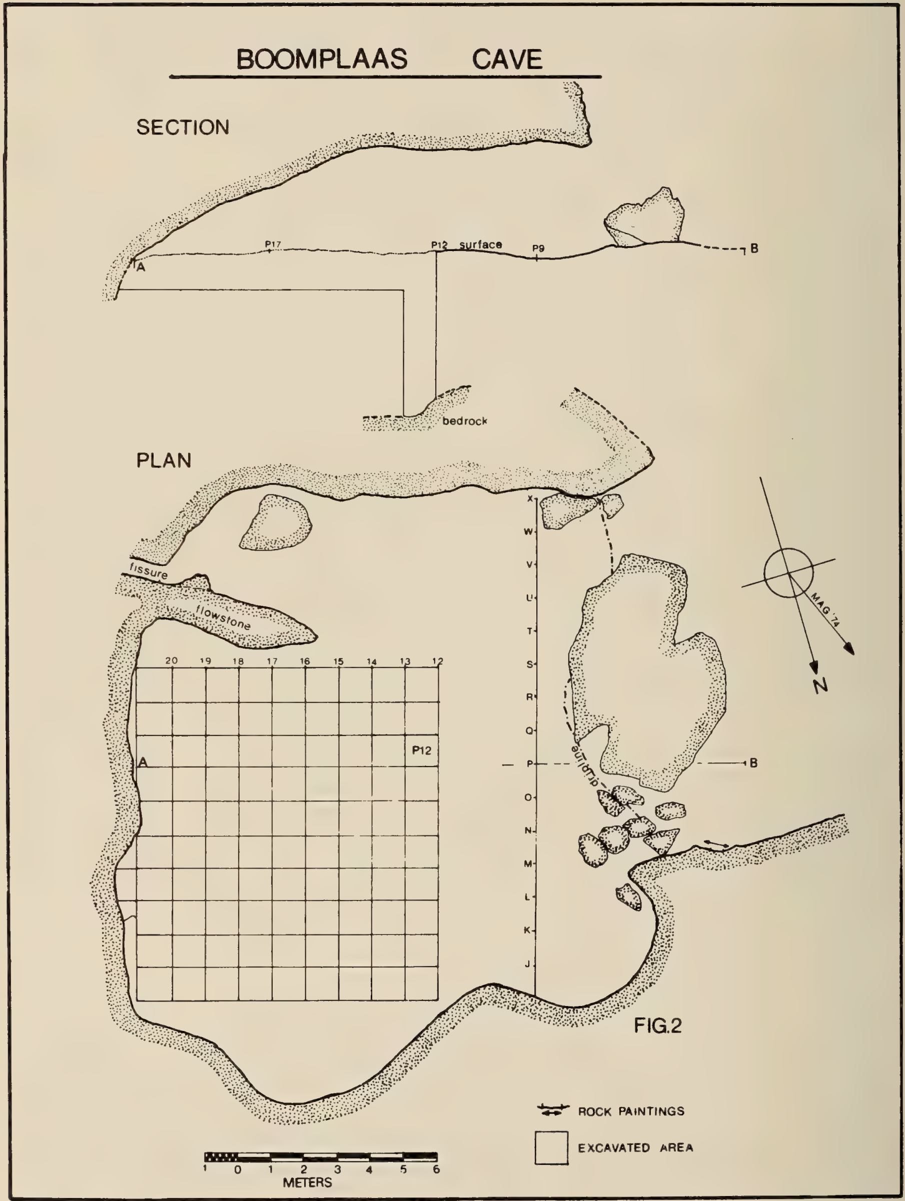

Fig. 2. Plan and section of Boomplaas Cave showing the grid and excavation area.

than 40 000 years and beyond standard radiocarbon age determination. Major disconformities are not apparent and the site affords a more complete Holocene–Upper Pleistocene sequence than is yet known from the southern Cape and it includes occupation horizons in the time range between 40 000 and 15 000 years. A minor stratigraphic disconformity has been noted in this time range at Boomplaas but may be a depositional break of only some 2 000 to 3 000 years. It is, however, important in relation to the cultural sequence.

The sequence at Boomplaas can be viewed in different terms, from the aspect of the depositional history, the litho-stratigraphic units, from the aspect of the organic remains, the biostratigraphic units, and from the aspect of the cultural traces of preserved features and artefacts, the culture-stratigraphic units. A detailed report on investigation is in preparation for publication elsewhere and only some of the major features are discussed here. As might be expected in any long-sequence cave-fill the lithological units are varied and complex. There is, however, a constant tendency for the sand fraction column samples through the sequence to show a trimodal particle size distribution. This may reflect a balance in the contribution to the deposits from different sources. In the build-up of the deposits a fissure opening to the surface in the rear of the cave and material transported by human and natural agencies through the mouth of the cave are of importance. There is, in addition, contribution of a coarse element, roof spalls and rock tumble, to the deposit. The most notable effect of human occupation is the increase in organic material and ash. Red-brown loams form with lower intensity of occupation and characteristically have a relatively high micro-fauna content. Three layers with high angular roof spall content mark changes in the stresses within the domed roof and are explicable as the result of frost fracturing. These can be placed in time and may have palaeoclimatic significance. An initial series of sediment samples have been studied by J. J. N. Lambrechts.

The sequence includes well-preserved fauna from all levels, but plant remains are preserved in humified form from the Holocene horizons only. The mammalian fauna is under study by R. G. Klein and additional observations on the micromammalian remains have been made by V. Scott and T. Pocock. The expectation in the Holocene–Upper Pleistocene time range is that the mammalian fauna will be largely composed of extant forms. Interest in the fauna lies in the main in its potential as a reflection of environmental change and changing hunting preferences. In the occupation horizons it can be postulated that the main source of larger mammalian faunal remains is the return of man-made kills to the site. Non-occupation horizons also include larger mammal remains, the result of carnivore predation and natural deaths, and are of principal importance for the study of micro-fauna and changes in patterns of owl predation.

Following out of Klein's study of the samples of mammalian fauna from the current stage of excavation progress it is apparent that there is cyclic change through time between assemblages dominated by grazing and browsing antelope.

It is reasonably well established that the main adaptation of Holocene hunter–gatherers was to the hunting of small browsers and it can be argued that this reflects the disappearance of a niche for grazers through increased shrub and bush cover in the Holocene in the fynbos areas (Deacon H. J. 1972: 34; Klein 1974: 273). In the Boomplaas sequence the Holocene is marked by the occurrence of marine shell, an indication of the eustatic recovery of sea-level to a point that brought the coast within range of foraging activities of the cave users, and again in the dominance of grysbok in the faunal remains. In the later and middle Upper Pleistocene, in a time range extending back to more than 40 000 years, changed environmental conditions are indicated by the absence of grysbok and the presence of wildebeest. Still earlier in the Upper Pleistocene grysbok are again the dominant antelope. Although human selection may be a factor contributing to this cyclic pattern, real changes in the environmental mosaic are suggested. A test is afforded by the micro-fauna remains from owl pellets and preliminary studies indicate that the micro-fauna will be a useful source of independent information on past environment. Rich accumulations of micro-fauna are a feature of some stratigraphic units in the middle part of the sequence and there are modern owl roosts in the same limestone outcrop for comparative study.

A control study of the modern vegetation cover of the area has been initiated by R. O. Moffett both for the identification of plant remains recovered and to aid in understanding the direction and amplitude of past vegetation changes. Thus far this part of the study has contributed a collection of over 400 plant species to the district herbarium in Stellenbosch. Limited fragmentary humified macroscopic plant remains have been recovered from the upper metre of deposit. Little success has thus far been achieved in the study of pollens from cave sites anywhere in South Africa and at Boomplaas an initial series of samples analysed showed negative results. At present the prospects for the study of micro-plant fossils must be seen as low.

The cultural sequence has been best studied in the topmost units and the upper 80 cm of deposit (CBM, DGL and BLD 1–2A, Fig. 3) represent the use of the cave as a kraal. This accumulation of banded calcined dung and sandy loam layers dates to the last 1 700 years and is related to the appearance of pastoralists in the region. Associated with the herding way of life is the introduction of pottery and the construction of relatively elaborate hearth features (BLD2), some of which are packed with stone. Kraal sites of early herders in the Cape have low archaeological visibility, making this occurrence significant. There are very limited associated artefacts in the upper unit.

Below a uniform calcined dung band (2A) forming a floor to the unit is a carbonized and humified dark brown marker horizon (BLD3). This would appear to have been formed through the burning of dung accumulation overlying the former natural surface layer of the cave floor which was littered with woody and leafy wind drift. The horizon includes a range of artefactual materials typical of the microlithic Holocene industry that is found along the length of

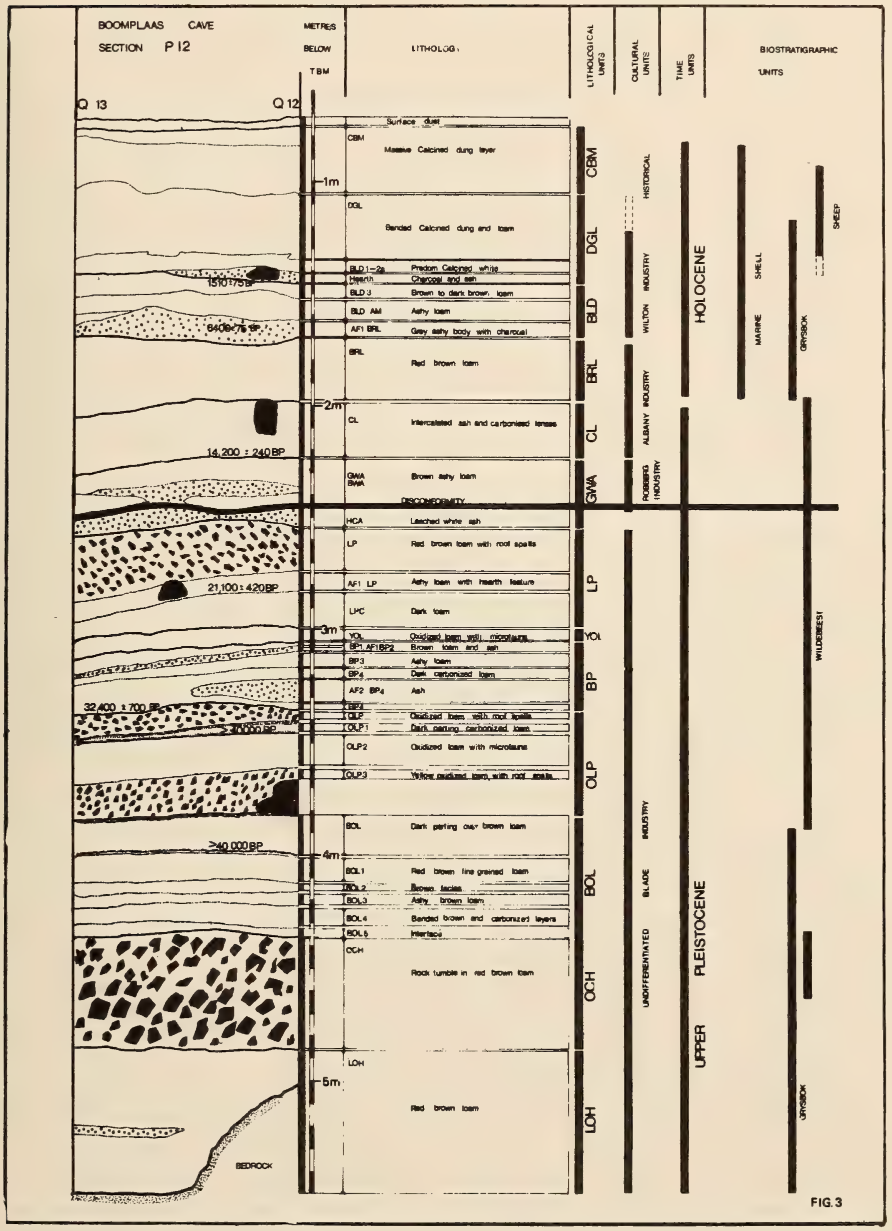

FIG. 3

Fig. 3. Section through the Boomplaas Cave deposits showing the lithology, dating, cultural and biostratigraphic units.

the eastern zone of the Cape Folded Mountains. Numbers of pits lined with *Boophone disticha* leaf and grass are cut from the base of this layer into the underlying deposits in the central area of the cave. These are storage pits and the few that have not been emptied contain fruits of *Pappea capensis*. This late Holocene practice of storing fruits can be suggested as related to the harvesting of oil rich fruits rather than the collection and storage of edible foodstuffs. At present the only comparable observations are from Melkhoutboom Cave where similarly oil rich but less palatable fruits were stored in grass lined pits. Although the plant remains are humified, the excavation technique was designed specifically to maximize the recovery of plant materials and it was apparent that few edible plant species are represented. A single corm of *Watsonia* and two *Hypoxis villosa* corms are amongst the limited sample of food remains thus far recorded from the pits. At this time level probably between 2 000 and 2 500 years B.P. the cave would seem to have served as a base for a specialized and seasonally restricted activity. Ashy material (BLD3AM) underlies the marker horizon and at least two distinct surfaces representing short term occupations could be distinguished on the occurrence of humified woody litter in the unit. Below this upper Stone Age occupation complex is a coarse sand loam horizon with abundant micro-faunal remains (BLDBL). This would seem to represent a break in occupation. At the base of the micro-fauna rich layer is a floor (FBL) exposed thus far over some 30 sq. metres that shows a low density scatter of fauna, artefacts and humified plant remains. Below this floor is a series of discrete occupations associated with extensive lenticular ash bodies one of which (AF1 BRL) is dated to 6 400 ± 75 (UW 306). Area stripping of the interdigitating ash lenses is the stage reached by larger scale excavation at the present and further comments on the culture-stratigraphic succession are restricted to information gained from the excavation of the P12 sounding.

A red brown sandy loam (BRL) underlies the ash lenses developed in the deposits detailed above. While not devoid of traces of occupation it represents a period of low intensity utilization of the cave by man. The Pleistocene–Holocene boundary is represented in this layer by the disappearance of marine shell manuports. A complex of ash lenses and intercalated dark humic loams (CL) developed to a thickness of 30 cms underlies the end Pleistocene red brown loam. The base of this unit is dated to 14 200 ± 240 (UW—301) and the whole is by contrast a phase of more intensive site utilization. The cultural materials from this unit are referred to the Albany Industry in the local culture-stratigraphic terminology. A further late Upper Pleistocene occupation (Robberg Industry) is represented in the underlying depositional units (GWA–BWA) that in turn bottom on a disconformable surface. The disconformity as noted correlates with a major cultural discontinuity and below the disconformity the artefact industry is macrolithic in character. The latter industry for obvious sampling limitations has been designated as an undifferentiated Upper Pleistocene blade industry but in all probability represents a complex of industries.

The Holocene and late Upper Pleistocene Stone Age sequence at Boomplaas and other occurrences in the Southern Cape appears to represent a pattern of three stable adaptations each with a 6 000–8 000 year duration during which set norms of technological and subsistence behaviour were established. It is a time range of marked environmental change and each adaptation appears to be an adjustment to gradually changing environmental conditions within a single level of human behavioural potential (Deacon H. J. 1974).

The upper Pleistocene cultural sequence is not well understood in the Southern Cape. Goodwin (1930: 565, 1933: 517) described it as comprising three content units, the Mossel Bay, Still Bay and Howieson's Poort cultures, but he noted difficulties in precise definition of these variants or variations. The excavation of new sequences and the re-examination of previously excavated sequences is under way but many problems remain (Klein 1969: 134). The Boomplaas sequence offers the potential for the study and possible resolution of some of the problems of the Upper Pleistocene cultural sequence and this indeed is one of the more important aims of the research programme. An indication of the value of the site in this regard is given by the recognition of a circular stone hearth feature in a dark ashy loam excavated as AF1/LP and dated to 21 100 ± 420 (UW-300). This represents a short term occupation horizon, one of several surfaces on which cultural and faunal remains have accumulated and which are separated by non-cultural deposits. The implication for the excavator is that a very fine distinction between occupation horizons can be made. This has not been possible at some other sites, as for example in the lower part of Kangkara where the slow rate of accumulation of deposits and intense weathering has resulted in a much condensed sequence.

Interest in the Boomplaas sequence is then from a number of aspects. What was sought in the initial reconnaissance excavation in the Langkloof was minimally a cultural sequence extending into the Upper Pleistocene with good preservation of fauna. There are few known occurrences in the region that fulfil this condition. The Boomplaas Cave has well preserved faunal remains throughout and in addition the sequence encompasses much of the Upper Pleistocene. The stratigraphic separation of different occupation levels is seen as important in the study of how cultural residues accumulate on and are distributed over temporary stable surfaces exposed for varying periods during the build up of a series of cave deposits. Generally described as 'floors', these do not always have the same unit value in terms of occupation.

CONCLUSIONS

This is a preliminary statement on the Langkloof project which is seen as a long term study. It is estimated that the excavation of the site which is the present major focus, Boomplaas, Cave will involve fieldwork over the next 15 years. However, concurrently with this excavation, studies will be made of other Holocene and Upper Pleistocene sequences and efforts devoted to the study of particular problems. An example of problem orientated research forming part of the overall project is that directed at the study of *Watsonia* and other geophytes which were dietry staples of Holocene gatherers. On the evidence from Boomplaas Cave this work needs to be extended to include oil rich seed producing species. The object is to gain an understanding of the adaptive advantages of the exploitation of certain specific resources and ultimately a more deterministic explanation of aspects of behaviour. While Holocene studies are more advanced and problem orientated research is possible, within the lesser known Upper Pleistocene time range much more basic descriptive observations are needed.

ACKNOWLEDGEMENTS

The Langkloof archaeological research project has been supported by the Fund for Scientific Research (University of Stellenbosch) and the Human Sciences Research Council. The authors acknowledge the interest and co-operation of A. Botha, J. Deacon, R. G. Klein (University of Chicago), J. J. N. Lambrechts (Soil Science Department, University of Stellenbosch), T. O'C. Maggs (Natal Museum), R. O. Moffett (Botany Department, University of Stellenbosch), B. Adams, P. P. H. Hamel and F. B. Silberbauer (Archaeology Department, University of Stellenbosch), V. Scott, M. Wilson (South African Museum) and the Municipality of Oudtshoorn and their staff at the Cango Caves.

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EXPLORATION ARCHAEOLOGY OF THE KAOKOVELD AND SOUTHERN ANGOLA AND POTENTIAL AUSTRALOPITHECINE SITES IN THE SERRA DA CHELA MASSIF, SOUTHERN ANGOLA

By

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(With 5 figures, and a note by R. G. Welbourne)

ABSTRACT

The main characteristics of surface archaeology in and near the Kunene River on the border of Angola and South West Africa are described. No living-floors or organic materials were observed but stone artefact sites are abundant. The pre-Cenozoic history of the Kunene may be inferred from tillite deposits which were located.

A potential australopithecine site, mapped by F. Mouta, on the Serra da Chela was visited and is described.

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INTRODUCTION

Archaeological exploration is progressively revealing the south-western side of southern Africa as a potential Early Hominid discovery region. The discovery of Tertiary land mammals at Elisabethvelder on the South West African coast was followed by P. V. Tobias's announcement of the discovery of a possible Hominid femur fragment in a dolomite fissure at Berg Aukas in South West Africa. In January 1975 the author was able to investigate a potential Hominid site at Leba on the Serra da Chela Massif in Angola whose discovery was announced by R. A. Dart in 1950 (Dart 1950).

In 1958 H. Martin kindly offered the author a seat in a vehicle bound for the Kaokoveld in South West Africa, where he was to accompany an expedition from the University of Cape Town by E. Simpson. This was accepted with pleasure, in the knowledge that in 1954 C. K. Brain had discovered an Earlier Stone Age site near the Kunene River gorge, west of the Marianfluss tributary, in the arid western portion of the river's course (Brain 1959) (Fig. 1 Site 1).

The intention was to search the eastern portion of the Kunene Valley between the Marianfluss and the Ruacana Falls in the hopes of discovering

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Ann. S. Afr. Mus. **71**, 1976: 215–224, 5 figs.

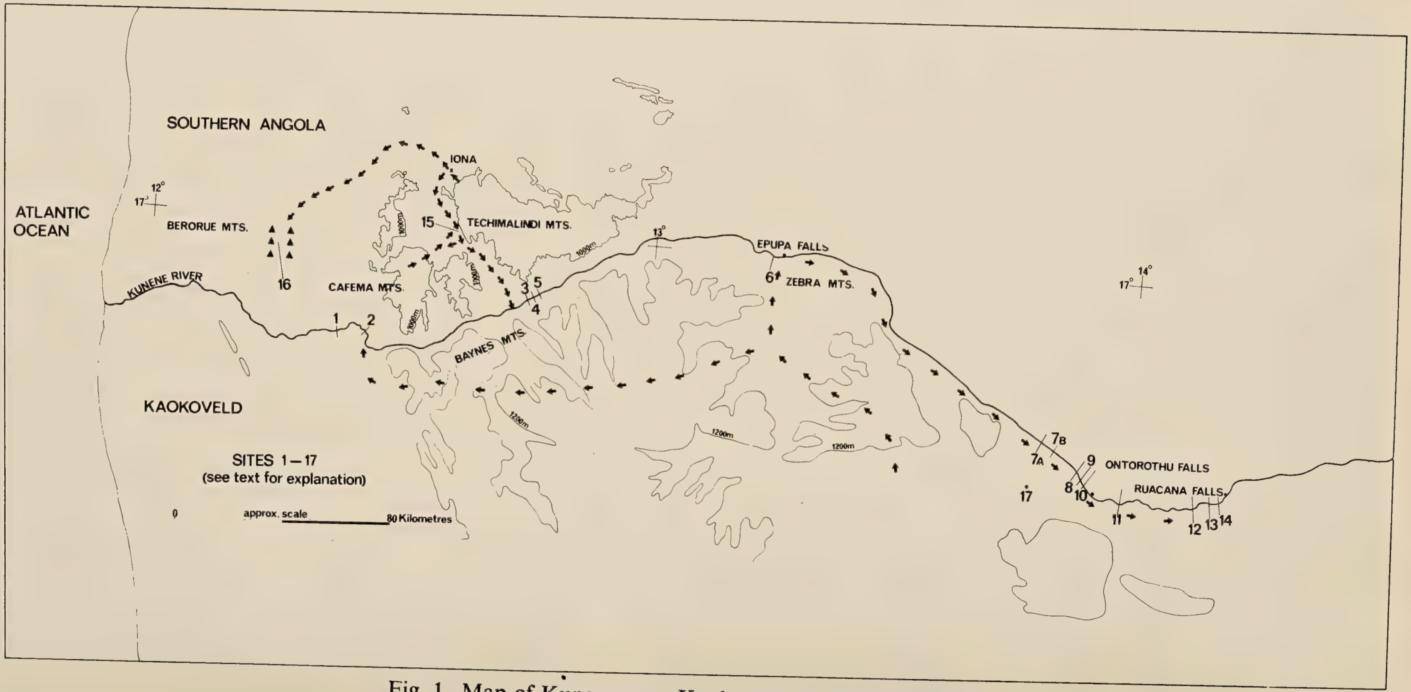


Fig. 1. Map of Kunene area, Kaokoveld, southern Angola.

potential Early Hominid localities of the living-floor variety, preserving both organic materials and artefacts. The author was able to study sites on the Kaokoveld bank between C. K. Brain's Kunene Gorge site and the Ruacana Falls, and for a month was accompanied mainly by D. Toerien.

In January 1975, through the kind offices of D. J. Malan, Prospecting Manager, Geology Department of the Johannesburg Consolidated Investment Company, J. de Villiers and P. Cochran and accompanied by N. Rosendal, the author walked from Iona to Otjimborongbongo on the Kunene River on the Angola bank and was able to confirm the essential features of the alluvial sequence of the Kunene River previously observed in 1958 by identifying three separate profiles of the river at Sites 3, 4 and 5, indicated on Figure 1. B. Huntley, Chief Game Warden of Angola, kindly drove the party to sites in western Iona where Iron Age observations were recorded (Fig. 1 Site 16).

At no site in the Kunene Valley or in the territories visited north or south of the river did the author observe a single Stone Age living-floor or Stone Age site with organic materials, although a lens of Earlier Stone Age artefacts near Cambino (Site 15 on Fig. 1) may be the surface of an intact Earlier Stone Age camp. At Site 16 on the flats at the eastern edge of the Berorue Mountains Iron Age floors with bone and charcoal were observed, possibly ancestral to the present-day Himba now concentrated well to the east of the Berorue. The author was, however, able to make the following observations in the Stone Age context (see Fig. 2).

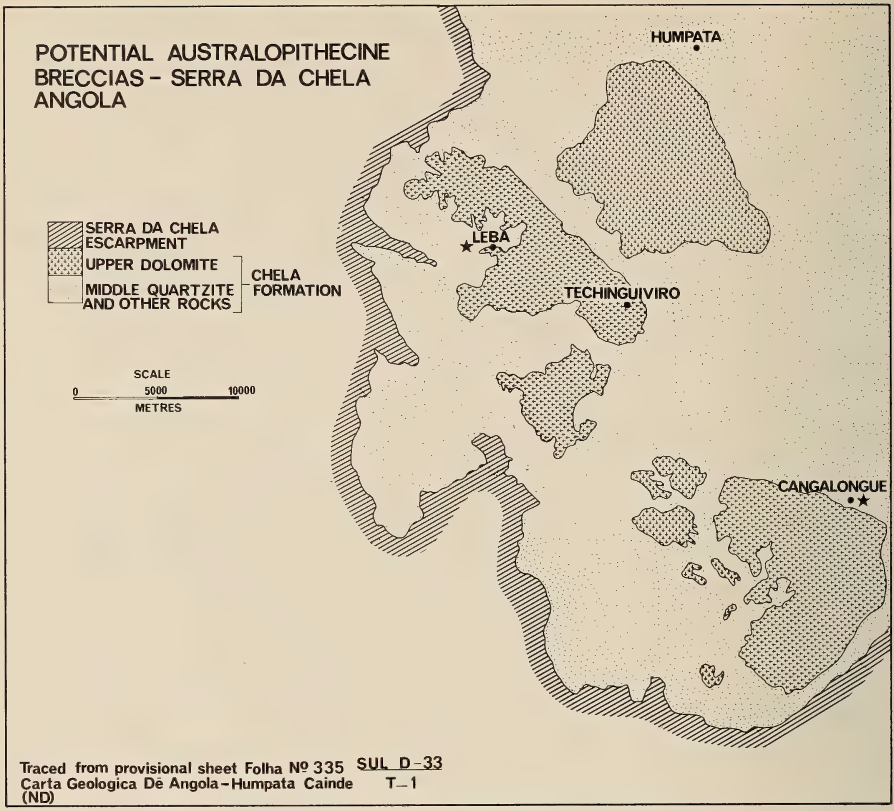
GRAVELS

Well-rounded gravels, presumably of alluvial origin, accumulated in lenses nearly 2 metres thick at localities tributary to the Kunene, such as Site 17 (north of Ehomba Mountain) which are not forming today. Gravel deposits at localities such as Site 17 apparently accumulated during the Acheulean and Sangoan occupation of the area. Site 17 may represent a period of well-rounded gravel accumulated in the environmental history of south-western Africa similar to the deposition period represented at the Nakop River on the southern edge of South West Africa discovered by Brain in 1954 (Brain & Mason 1955).

The Kunene River today is transporting gravels in the arid environment investigated, but these gravels may well be partly derived from presumably Dwyka tillites abundantly represented in the Kunene Valley. The discharge for the transport of such materials is derived from the Highlands of Angola where present-day rainfall is of the order of 50 cm annually.

STONE AGE ASSEMBLAGES

The presence of substantial quantities of Acheulean artefact assemblages, possibly representing both Earlier and Later stages of the Acheulean development are located at Sites 1, 7A and 7B, 15 and 17, showing that the length of the Kunene Valley and adjacent territory was extensively used as a source of


POTENTIAL AUSTRALOPITHECINE BRECCIAS - SERRA DA CHELA ANGOLA
SERRA DA CHELA ESCARPMENT
UPPER DOLOMITE
MIDDLE QUARTZITE AND OTHER ROCKS
CHELA FORMATION
SCALE
0
5000
10000
METRES
HUMPATA
LEBA
TECHINGUIVIRO
CANGALONGUE

Traced from provisional sheet Folha Nº 335 SUL D-33
Carta Geologica Dē Angola-Humpata Cainde T-1
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Fig. 2. Map of Serra da Chela potential australopithecine sites.

food and raw materials by Acheulean Man. Site 17 is the only Sangoan locality that was observed.

In addition to Earlier Stone Age data, Middle Stone Age surface assemblages, ranging from assemblages resembling the Cave of Hearths Bed 4 assemblage, through to assemblages resembling the Cave of Hearths Bed 6–9 assemblage, especially at Sites 3 and 6, suggesting the occupation or use of the Kunene Valley by hunter–gatherer communities technologically related to the Cave of Hearths Middle Stone Age people. Later Stone Age assemblages resembling both Orange Free State Earlier and Later Smithfield assemblages are present, but not in substantial quantities. Later Hominid prehistory may be recorded in the numerous possible cave sites observed from aircraft north of Espiniera, near Iona (Fig. 1).

DWYKA TILLITES

The most spectacular feature of the history of the Kunene Valley is demonstrated by horizontal, or nearly horizontal, surfaces of Dwyka tillite, frequently clad by calcrete beds, exposed as vast sheets surfacing the tillite which plugs the Kunene Valley from at least the Ruacana Falls downstream to Otjimborongbongo. The Kunene tillites have been discussed by H. Martin (1953) (Sites 3 to 14). Accurate measurements of the heights of these surfaces above the present Kunene could not be made, but the author's estimates suggest that substantial horizontal surfaces are preserved from heights approximately 50 metres above the Kunene. The finest exposures of these surfaces may be seen in the approximate 30 km length of the Kunene downstream from the Ruacana Falls.

The clearest relationship of the Dwyka tillite to the earlier rocks of the Kunene Valley was observed at Otjimborongbongo where the contact between the Dwyka tillite filling and the older rocks of the Kunene Valley was clearly presented.

The Kunene Dwyka tillite is capped by immense calcrete sheets up to 4 metres thick, which also overlie other deposits in or near the Kunene Valley. The calcrete sheets may yield environmental data if a suitable chronometric dating technique could be developed.

The Kunene River therefore provides a parallel to the Vaal River as a stream course owing its origin in part to Dwyka Glaciation, or even earlier erosion (King 1951: 233). The glacial origin of both the Vaal and the Kunene valleys is clearly evident in the fillings of tillite observable in both valleys, but best preserved in the more arid environment of the Kunene River.

The Kunene tillites provide the main evidence for Dwyka glaciation in the valley, but, in addition, landscape morphology bears traces of glacial erosion. From the north summit of Otjihipa (approximately 1 500 metres) (Fig. 1 southeast of Site 2), the author was able to observe remarkable mature hanging valleys about 700 metres above the Kunene, on the south slopes of Cafema Mountain presumably representing the truncation of pre-Dwyka valleys by the main thrust of Dwyka movement supposedly in the direction of the Kunene flow today.

POTENTIAL AUSTRALOPITHECINE SITES ON THE SERRA DA CHELA MASSIF

In 1950 Raymond Dart published a short note on breccia deposits near Humpata in Angola on the Serra da Chela Plateau reported to him by Merlin W. Ennis (Dart 1950). Late in January 1975 the author was able to visit Leba, one of the breccia sites on the Serra da Chela Escarpment published by F. Mouta (1954) (Section and Plan, Figs 4–5) and is particularly grateful to P. Cochran for making arrangements for this visit.

In 1954 F. Mouta, quoting C. Arambourg, noted the presence of the following mammals at the Serra da Chela dolomite quarries located at Leba, Nandinhba and Kangalongue (Fig. 3):

1. Machairodont
2. *Taurotragus* cf. *oryx*.

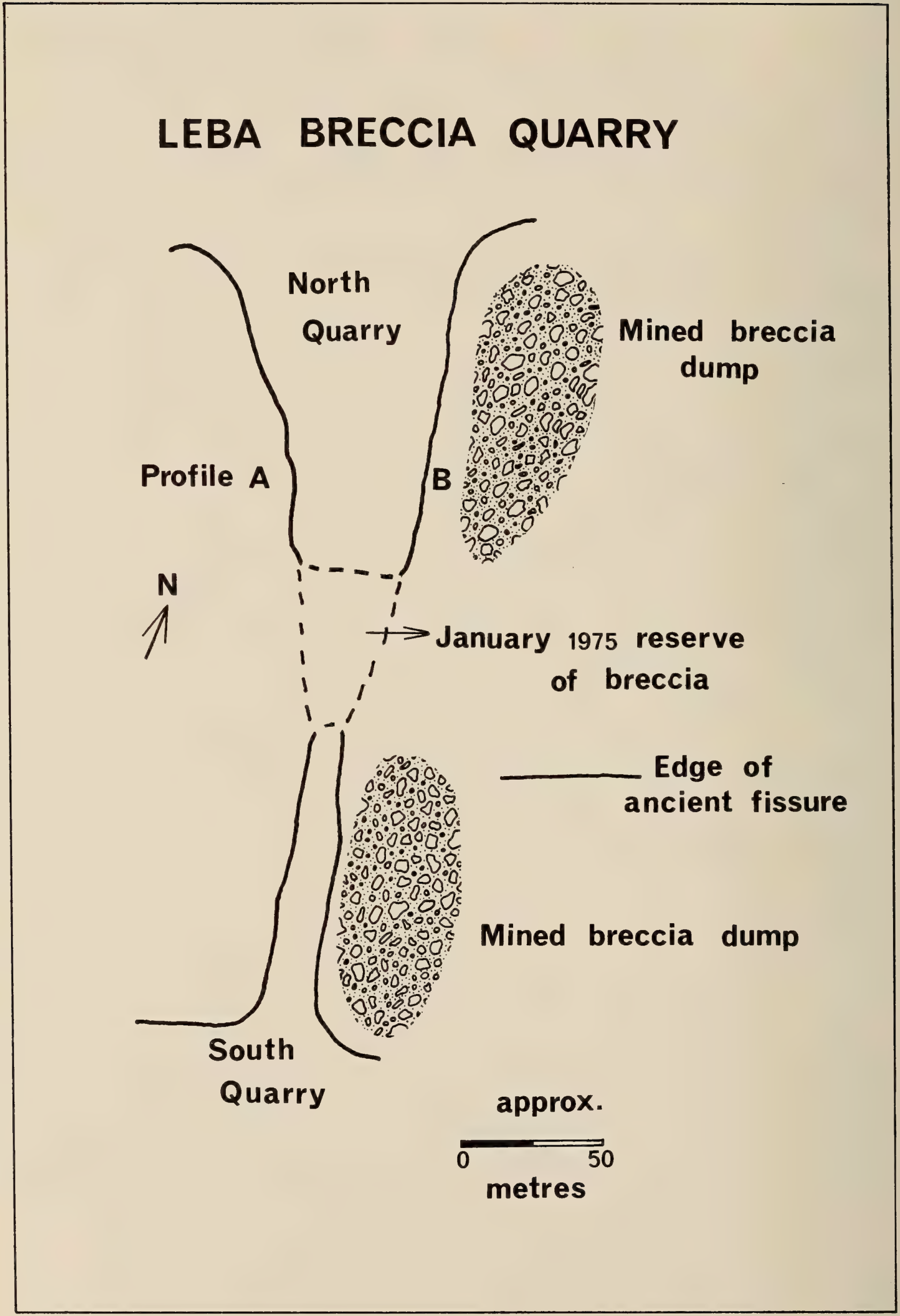

Fig. 3. Plan of Leba Quarry.

3. *Cricetomys* cf. *gambianus gambianus.*
4. *Dinopithecus ingens*
5. *Papio* sp.

Arambourg identified the fauna as 'pertaining to Early Quaternary' (Mouta 1954). Very similar forms are now known to occur with australopithecine remains at Sterkfontein, Swartkrans, Kromdraai, Makapan Limeworks, Taungs and Olduvai Bed I. (See note by R. Welbourne.)

The position of the breccias in the Serra da Chela dolomites was first established by F. Mouta in the late 1940s. Mouta located breccia deposits in the dolomites which are exposed resting directly on quartzite sandstones on the Serra da Chela Plateau analogous to the superposition of Dolomite on Black Reef Quartzite in the Transvaal. In January 1975 the writer visited the Leba quarry and drew the sketch plan and section illustrated in Figures 4 and 5.

The Leba fissure is simply the remains of a deep crack developed along the joints of the dolomite, possibly early in the Cenozoic. Tertiary erosion removed the surface dolomite to expose narrow cracks at sites such as Leba. Deep cracks in a game-rich area may have acted as animal traps, which may explain the presence of the bones of a possible large elephant reported to the writer by the quarry manager in January. The Leba quarry could therefore have functioned for many hundreds of thousands of years as a natural game trap. The presence of a fauna elsewhere in south and east Africa associated

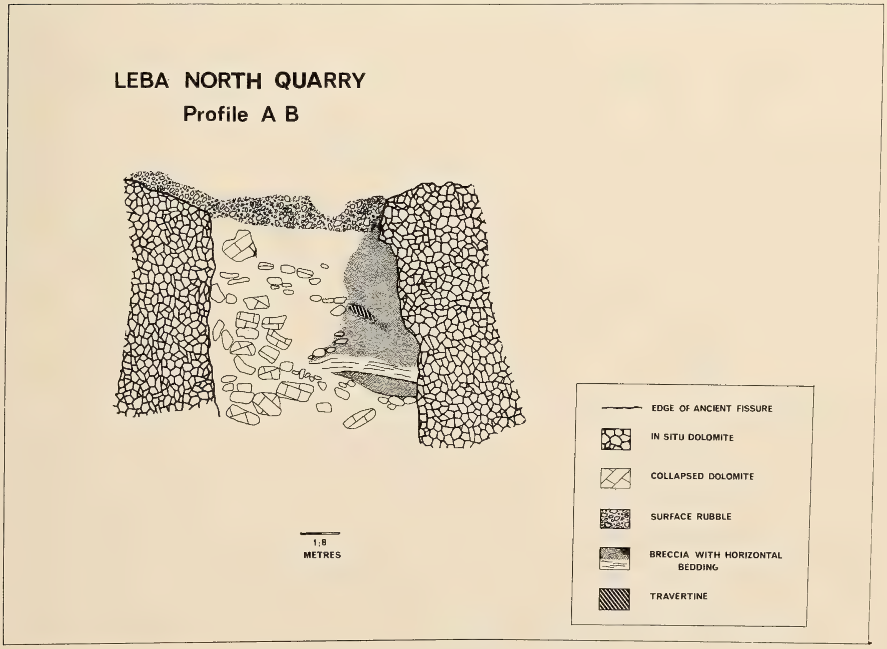

Fig. 4. Profile AB, Leba North quarry.

with australopithecine hominids suggests that a thorough examination of the Serra da Chela dolomite breccias would be eminently worth while.

Plans and sections of the Leba dolomitic fissures are easily observed as a result of extensive travertine quarrying which is continuing in 1975. The general appearance of the Leba dolomitic fissure environment is similar to the limestone caves environment in the Makapan Valley. The Leba travertines have been mined along a crack in the dolomite several hundred metres in length. At least several hundred tons of breccia are available to scientific research in dumps (Fig. 5). The breccia has been dumped on the side of the quarry in exactly the same way as the breccia was dumped outside the Makapansgat Limeworks quarry. A surface examination of the breccia disclosed a few fragments of bone but it is clear that the proportion of bone to breccia is very low. No substantial accumulations of bone were observed in the breccias, both *in situ* and in the rubble heaps.

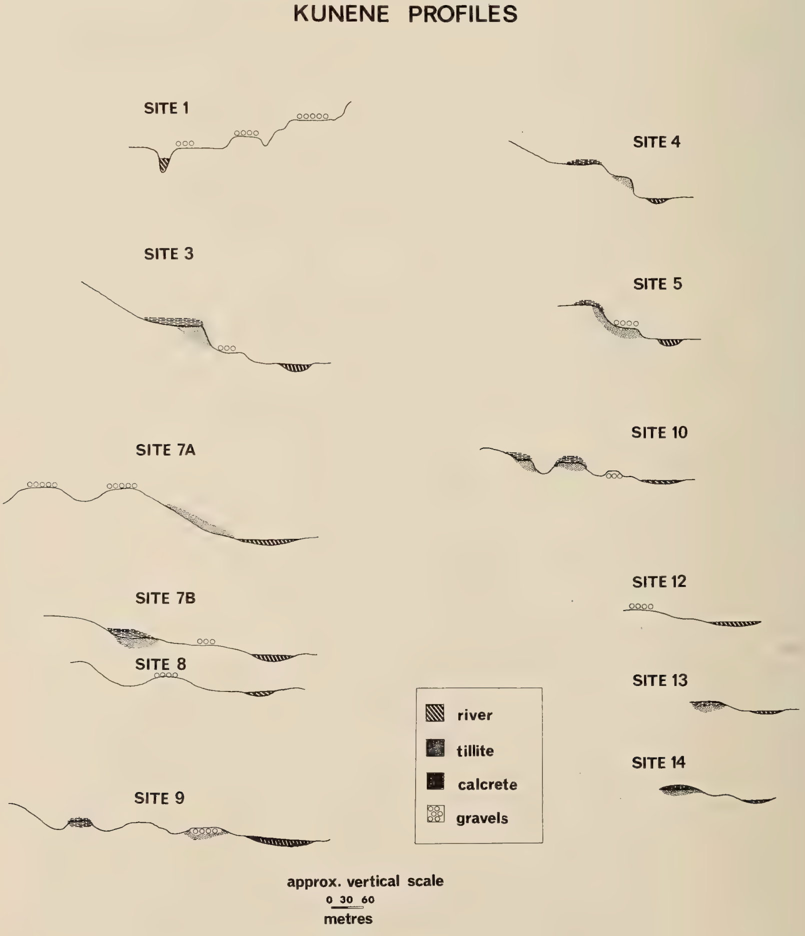

Fig. 5. Kunene River profiles.

Time did not permit a visit to the other potential australopithecine breccias at Nandinhba and Kangalongue or Techinvinguiro. Nevertheless sufficient information is available both in the literature and from informants in near-by Sa da Bandera to indicate that the dolomitic caverns and fissures of the Serra da Chela plateau offer a rich potential hunting-ground both for early and late hominid prehistory.

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REMARKS ON THE FOSSIL FAUNA OF THE SERRA DA CHELA

By

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The fauna from Serra da Chela, identified by Arambourg, has been listed by Mason as follows (see Mason report):

1. Machairodont (extinct sabre-tooth cat).
2. *Taurotragus* cf. *oryx* (the modern eland).
3. *Cricetomys* cf. *gambianus gambianus* (a living species of rodent widely distributed in warmer parts of southern Africa).
4. *Dinopithecus ingens* (an extinct giant baboon).
5. *Papio* sp. (the modern baboon).

The last identification, of *Papio* sp., may be in error. Perhaps the correct genus is the extinct one, *Parapapio*, which occurs at Sterkfontein and Taungs. Freedman (1957: 160) remarks that teeth of these two genera are indistinguishable.

Machairodont fossils have been recovered from Makapan Limeworks (Ewer 1956), Sterkfontein, Swartkrans and Kromdraai (Ewer 1955), and from Olduvai Beds I and II (Leakey 1965).

Dinopithecus ingens was described from the type site, Schurweberg, Transvaal, by Broom in 1937. Swartkrans has yielded 37 specimens (Freedman 1957).

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KEYNOTE ADDRESS

COMPARISON OF AUSTRALOPITHECINE-BEARING DEPOSITS IN EASTERN AND SOUTHERN AFRICA—A NEW LOOK AT A SIXTEEN-YEAR-OLD PROBLEM

By

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ABSTRACT

The historical background to hominid studies in eastern and southern Africa is outlined together with the contrasting environmental/palaeoenvironmental setting of the two areas. Parameters operating in favour of hominid studies and those operating in a contrary direction are analysed for the two areas. Geomorphology is rejected as a basis for dating. Although the deposits and their contained faunas in the two areas represent very different conditions of preservation, the contrasting bodies of evidence are complementary. Both must be combined to obtain maximum value from the hominid record of either area. The last word lies with the fossil hominids.

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INTRODUCTION

I am not sure what is implied by the term 'Keynote Address'. It appears to be something between a clarion call to rally the troops and the last trump! However, there is only need to rally troops when they are retreating in confusion and SASQUA seems to be in good heart. Clearly the last trump on Quaternary or hominid matters is still far off.

I think it is appropriate and timely to sound a 'half-time' keynote by reviewing critically the position reached in the investigation of Australopithecine-bearing deposits in eastern and southern Africa. The review will attempt to highlight differences of setting and of approach and hence in the nature of the results obtained in the two areas.

HISTORICAL BACKGROUND

The African continent is unique in the field of studies of man's antiquity. It has yielded the longest and most complete hominid fossil record and the longest sequence of archaeological traces of man's early technological development. There is good evidence of occupancy of Africa south of the Sahara by

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Ann. S. Afr. Mus. **71**, 1976: 225–237.

hominoids since early Miocene times, some 18 to 20 million years ago. A hominid line is generally thought as being separately discernible from about 14 million years ago. There are many long gaps in the early part of the record but the later phases of the hominid story are remarkably well covered for the period from about 3,5 million years ago to the present day. Artefact occurrences ranging back through some 2,5 million years are known and still earlier traces seem likely to be discovered in the near future.

It is only 50 years since Raymond Dart's prophetic publication in February 1925 announced the finding of the Taung child and the birth of the first of the Australopithecine line. Pioneer investigations during the 1930s at the Transvaal sites and the more sophisticated post-war phase which continues up to the present day need no further documentation here. Publications by Dart, Broom, Robinson, Brain, Tobias and many others tell their own story.

It is important to note that brief though 50 years may seem in scientific investigation, indeed my own life span is only a few years less than that of the taxon *Australopithecus*, the East African research has a much shorter time-base. It is barely 16 years since Dr Louis and Dr Mary Leakey found the skull of *Australopithecus* (*Zinjanthropus*) *boisei* at Olduvai Gorge in Tanzania. Only a single milk molar had been found prior to the discovery of 'Zinj' in 1959. Since his discovery the whole tempo of Quaternary research has quickened perceptibly. The boost to funds for research resulted in greater numbers of workers and in the development of more refined techniques. The mushroom-like growth can be judged from the numbers of hominid specimens recovered from the various East African rift valley localities during the last few years:

TANZANIA	Olduvai	50	since	1959
	Laetolil	12	since	1974
KENYA	Baringo	6	since	1966
	East Rudolf	125	since	1969
ETHIOPIA	Omo	182	since	1968
	Afar	50±	since	1973

A total of about 425 hominid specimens has been recovered in 16 years. The research has been both interdisciplinary and international and hence is an ideal subject for review at a SASQUA meeting.

CLIMATIC CONFUSION

By a strange coincidence it is also 16 years since the first moves were made towards the abandonment of the widespread use in Africa of the notional system of climatic–stratigraphic pigeon-holes based, in theory, upon four pluvial and three interpluvial periods. The worst aspect of this ill-founded sequence had been its misuse for 'dating' as a correlative of the familiar but equally precarious four glacials, with three interglacials of north temperate areas. Critical studies were carried out by Cooke (1958) from a base in South

Africa and Flint (1959) from a North American north temperate viewpoint. They showed that convenient though these pigeon-holes might seem, the evidence for their existence rested on insecure foundations (one could also say 'formations'), even in their alleged type areas.

Since that time African Quaternary stratigraphers have restricted themselves to the use of *normal* lithostratigraphic, biostratigraphic and geophysical/geochemical dating methods for correlation and classification rather than relying on climatic inference. This has involved a shift away from what has become accepted practice for Quaternary studies in temperate areas of other continents. However, it marks a return to what is the standard approach for most of the pre-Pleistocene geological column.

In addition to turning away from Quaternary pluvials as a panacea for stratigraphic correlation, recent research has shown that the Pliocene in Africa was not a time of universal and extreme aridity. As more evidence of hominids and of their activities becomes available for the Plio-Pleistocene it is important to emphasize that: 'Attractive though the idea may have seemed, human strength of character was neither tempered in the heat of a Pliocene drought nor quenched in the Pleistocene pluvials' (Bishop 1976).

EAST AFRICA AND SOUTH AFRICA

Following the general background considerations of the preceding two sections it remains to compare, and where necessary contrast, the geological setting of the principal Australopithecine-bearing deposits in eastern and southern Africa.

EAST AFRICA

The Gregory rift from the Omo Valley of Ethiopia southwards to the vicinity of Olduvai Gorge in Tanzania contains unique sequences of fossil mammal and hominid-bearing strata in the Pliocene and Pleistocene time range. Work has recently been extended further northwards along the Ethiopian section of the rift to the Afar region. Several aspects of the region may be isolated as favouring, or acting 'for', the preservation and study of the hominid material.

'*For*'

Law of superposition. By application of the basic law of superposition, the relative positions of hominid fossils within rock sequences, and by inference through time, have been established within numerous local, well-exposed 'layer cake' successions in the rift valley. Even if isotopic dates are not available, relative dating is possible using stratigraphic mapping combined with careful collecting.

Geological mapping and strato-geometry. From a basis in geological mapping, correlations have been made, aided by air photography and satellite imagery and controlled by ground survey, between adjacent stratigraphic sections. The mapping has been aided by the presence of good marker horizons, in the form of time synchronous tephra or deposits derived from tephra without appreciable time lapse. (For definition of 'tephra' see Thorarinsson 1954, 1969; Westgate 1974). Throughout the Rudolf Basin, but especially in the Shungura Formation of the Omo Valley, at Olduvai Gorge and to a lesser extent in the Baringo Basin, mapping has been assisted by the presence of such 'tuffaceous' marker beds even when the source volcano lies outside the area of study.

Potassium–argon dating. In East Africa many lavas, together with sediments from predominantly volcanic sources and including some tephra, are potassium rich and have been dated by potassium^{40}–argon^{40} decay methods. Olduvai Gorge witnessed the first application of ^{40}K–^{40}Ar to the dating of rocks as young as Pleistocene by Evernden & Curtis (1961), in the Berkeley dating laboratory of the University of California. These dates were fortunately keyed into the strato-geometry of Olduvai mapped by Hay. Similar work has now been carried out in other areas of the rift. For example in the Baringo district detailed mapping was carried out for the Kenya Government by research teams directed by Bishop and King, based at Bedford College, University of London, for which dating was undertaken at the Cambridge University laboratory by Miller and the Institute of Geological Sciences by Snelling. When the combined results of such mapping throughout the Gregory Rift are integrated with numerous isotopic dates obtained from several laboratories a most formidable calibrated Plio-Pleistocene succession will be established.

Palaeomagnetic polarity studies and the development of a Plio-Pleistocene 'palaeomagnetic polarity time-scale' (Cox 1969; Cox *et al.* 1963; Watkins 1972). The work of Brock at East Rudolf, of Brock and Cox at Olduvai Gorge and Brown at Omo has already yielded consistent results (Brock & Isaac 1974; Brown & Shuey 1976; Brown 1976). These provide cross-checks for the potassium–argon data. In the Baringo area a thorough sampling for palaeomagnetic polarity determination has recently been carried out by a Liverpool University team of the long section of over 150 lava flow units from *circa* 14 m.y. to late Pleistocene (Dagley 1976).

Fission track dates. These have been little used in the Gregory Rift area although early work at Olduvai was undertaken by Fleischer (Fleischer *et al.* 1965). There is a tremendous potential for cross-checking potassium–argon dates (particularly on sanidines from pumices) against glass shards (representing fractured bubble walls) and on zircon crystals from the same tephra source. Such material has yielded consistent sequences of fission-track ages from New Zealand particularly in the range from 2,0 to 0,2 m.y. (Seward 1973).

Comparative studies of recent environments and processes. The patch-work of rift environments is worthy of mention as a further advantage. The whole rift valley graben has been for 16 or 17 m.y. a 'sump' region into which sediments have been decanted, including such odd-shaped sedimentary particles as fossils and, towards the end of the period, artefacts, as an integral part of the sediment. Phases of recurrent fault movement or the initiation of grid faults have exposed the sediments to erosion and scientific observation. Volcanic activity occurred intermittently but persistently—sealing sedimentary basins, diverting drainage lines and forming fresh catchments for water and sediment. Volcanicity contributed burial materials in the form of tuffs (both primary fall-out and secondary derivatives) that provided environments with a chemistry favouring the preservation and mineralization of bone. Similar deposits are still being formed, as for example the calcium carbonate rich tephra from the volcano Ol Doinyo Lengai in Tanzania.

This similarity between present-day and past volcanic products underlines the important function of the rift as an open air 'laboratory'. No study illustrates this better than taphonomy, although much remains to be done in this developing field. However, some 'burial laws' are already beginning to emerge, thanks to the studies of Behrensmeyer (1976) and Hill (Hill & Walker 1972), in both ancient and modern rift environments.

'*Against*'

There are, however, some factors that are unfavourable to hominid studies:

Limited sample size. The long sequences of superimposed fossil-bearing units in the rift are advantageous for the dating of hominid material but they have one major drawback. No large sample of hominid remains referable to one genus or one species has been found in, or on, a single stratum. Thus inferred variations within a taxon must be traced through time without the palaeontologist being able to study variability in a sample even approximating to a population from a single time-plane. Frequently only scanty and disarticulated remains are found, although they can sometimes be assigned to one individual.

Facies faunas and life and death assemblages. Fossil-bearing formations, members and beds can be traced over 50 to 60 kilometres (as for instance in the Omo Valley and at East Rudolf) with the aid of reliable marker horizons. However, change of facies may result in the sampling of 'facies faunas' representing different local environments of broadly equivalent age. Taphonomy (study of Burial Laws) plays an important role in helping to interpret such deposits. It is also valuable in showing the extent to which mammalian fossils, including hominids, have become 'bedfellows' only after death by being transported into one sedimentary environment although representing animals favouring different ecologies during life.

The differences in composition between the assemblages of fossil hominids from Omo and East Rudolf suggest different taphonomic selection in the two areas:

Numbers of Hominid fossil specimens

	Post Cranial	*Crania, maxilla, mandible (whole or part)*	*Isolated teeth*	*Total*
OMO (since 1967) . .	7	13	162	182
EAST RUDOLF (since 1969) . .	50	59	16	125

Some of the contrasts may reflect different methods of collection, but there seems little doubt that the principal differences result from different conditions of preservation.

SOUTH AFRICA

The South African ape-man bearing cave breccias also show factors that may be considered as acting 'for' or 'against' the scientific value of the hominid material.

'*For*'

Accumulation. Once caves in the dolomitic limestone are in communication with the surface they provide repositories where under the influence of gravity, water, mammalian and human agency, bones of animals that lived and died in the vicinity are accumulated.

Chemical environment. A limestone cave favours the preservation of bone structure. Some distortion may occur owing to compaction or through roof falls, but infiltration of calcium carbonate into the breccia matrix, and the formation of travertine layers assist rapid consolidation favouring the survival of bone and tooth.

Comparative studies. The existence in the same area of similar modern caves permits studies to be undertaken of the various processes involved in sediment or bone accumulation and mineralization.

Sites. The caves represent localized accumulations of bone from which large numbers of hominid remains have been recovered, e.g. over 600 specimens from Swartkrans represent at least 85 individuals (C. K. Brain, pers. comm.). Unfortunately, the time over which this number of specimens accumulated is not known. Nevertheless, it may be argued that once a cave is open to the surface and particularly if the cave mouth or shaft opening is attractive as a lair or habitation, infill is probably rapid. The fill includes biological and other material which falls or is washed in, roof fall, travertine and interstitial carbonate, together with animal remains and other items brought in. Some phases of infill have been recognized from changes in the sedimentation pattern. However, such accumulations are probably the nearest that a palaeontologist studying Plio-Pleistocene hominids approaches to having a large sample from a 'population' as they possibly span only limited periods of time. It is necessary to add a further caveat that the possibility of secondary solution and later infill cannot be ignored in a limestone area.

'Against'

Factors that are unfavourable to hominid studies are:

Cave bias. A cave fill may sample only a biased representation of the total biomass that lived in the cave area. Bias may be in the direction of selective eating and collecting habits or of preferences for a 'life style' in or near caves. However, 'pit fall' mechanisms probably serve to redress some of this otherwise selective sampling—even here, however, there is probably a trend towards natural selection of a sample biased toward the halt, sick, lame or just plain unwary.

Stratigraphic isolation. The former caves are now represented by masses of bone-bearing breccia that are stratigraphically isolated entities. They are volumes, rather than layers, of rock separated by virgin dolomite or by erosion from any surviving remnants of an original system of communicating caves or related deposits. The infills of individual caves have been analysed most elegantly by sedimentological and stratigraphic investigations (Brain 1958, 1976; Butzer 1974) and I am happy to note that Formations are being mapped *within* the caves as recommended in Bishop & Clark (1967), as outlined in papers read by Brain and Partridge at this conference.

Temporal isolation. The caves are isolated in time as well as in space. As yet no isotopic dating technique or other dating method *independent of the fossils themselves* has been successful despite persistent efforts to explore every possibility.

Correlation. Correlation between the individual cave sequences and faunas is therefore dependent upon comparison of fossil assemblages typical of the cave environments of accumulation. This involves elimination of purely local ecological differences and use of 'stage-of-evolution' as the criterion for establishing relative age. Some 'second-hand' dates have been derived by correlating the cave assemblages with other mammalian sequences already calibrated isotopically. This becomes particularly difficult when it involves extrapolation across distances of 2 500 kilometres or more (e.g. from Sterkfontein to Olduvai Gorge), from the southern part of a continental mass (latitude 26°S) to a more central situation almost on the equator (latitude 3°S). There are additionally the problems referred to above of relating the South African cave assemblages to East African open plain, lake shore or riverside 'mixed' assemblages.

Dating and correlation. It is important to differentiate with care between these two terms. Dating should be retained for the establishment of dates, measured in potassium–argon decay years or radiocarbon years. Correlation may be affected by use of lithological sequence, biological content, palaeomagnetic characteristics or by comparing isotopic dates established by similar methods. Correlation may yield 'second-hand dates' but these should not then be re-used for further dating.

An alleged geomorphological dating method. Recently Partridge (1973) attempted to use a geomorphological approach to derive dates for the opening of four South African former caves that have yielded hominids. This has not been referred to above as it is not a viable 'dating' method. The three major assumptions on which the method is based all have inherent problems:

ASSUMPTION I requires that a geomorphological datum, the African erosion cycle of L. C. King (1962), is a well-established morphological feature throughout southern Africa, occurs and is recognizable near each of the hominid-bearing localities, can be dated by extrapolation from its time of inception at the coast (in this case about 100 m.y. ago), was developed at a relatively constant rate, and has remained *virtually unmodified since its initial planation.*

ASSUMPTION II concerns migration of nickpoints related to L. C. King's Post African I cycle (dated as leaving the coast during Burdigalian times—about 20 m.y. ago). De Swardt (1974) criticizes the validity of this approach. Partridge assumes that headward erosion along three river systems (two major tributaries of the Limpopo flowing to an Indian Ocean base level and a tributary of the Orange River flowing to the South Atlantic) progressed at a sufficiently constant rate during the Post African I cycle to permit comparisons between the different rivers. The length of each section of river downstream from a cave situation is compared with total stream length in order to derive a measure of time elapsed.

ASSUMPTION III involves the establishment of time lapsed in widening the valley to produce cavern opening in the period since the nickpoint was opposite the cave site. Partridge lists further assumptions involving rectilinear valley flanks, down-cutting of the channel and regular retreat of rectilinear valley flanks. However, it is not certain that all the caves opened as a result of valley wall retreat as opposed to widening of joints communicating with the surface of an interfluve.

Assumption I calls for a number of subjective judgements but, apart from noting the critical comments of B. C. King (1958), Holmes (1965) De Swardt (1974) and Bishop (1966) these are not considered here. The problems raised by Assumptions II and III are sufficient to invalidate the method. Recent studies of modern erosion rates for rivers and slopes (e.g. Douglas (1969), Gibbs (1967), Young (1969), and recorded in various textbooks) make clear the variables involved. Widely different rates are obtained, depending upon the interplay of climate, aspect, slope and substrate.

Past erosion rates as recorded in the geological column are more difficult to quantify. However, attempts have been made which provide 'guestimates' ranging from 0,1 to 100 m^3/km^2/year (e.g. Clark & Jager (1969), Ruxton & McDougall (1967) and Dury (1972) cite further references to relevant work).

Other variables include change in ground cover while a slight change in climate in a semi-arid area grossly changes the sediment yield (Douglas 1967). Similar effects may be induced through removal of vegetation, however this is brought about. Variations in lithology, even those which are very local and not recorded in Partridge's assignment of his river profiles to four broad divisions of substrate, can greatly alter rates of headward erosion.

In brief, the variation observed in the parameters controlling the migration of nickpoints and valley flanks is so great that the geomorphologically derived dates cited by Partridge have no firm basis. One would welcome a dated sequence of South African hominid-bearing caves to set alongside the East African hominid chronostratigraphy. However, this attempt at geomorphological dating seems to be a case of the wish becoming father to the thought.

It is particularly unfortunate that in two recent papers P. V. Tobias accepts Partridge's dates as having 'implications' for the study of South African hominids (1973*a*, 1973*b*). In his *Nature* paper (1973*a*) he refers to the dates as only estimates. However, in an abstract prepared for the IX INQUA Congress (Tobias 1973*b*), they are quoted as if they are firm and reliable ages. Various other anthropologists are also beginning to make use of the geomorphic 'dates' as if they were reliably based.

However, it is important to note that although Partridge has described an interesting theoretical geomorphological model it has not found acceptance from geomorphologists as a working model that can be applied in the field.

Stage-of-evolution data. Correlations based on stage-of-evolution of the fossil mammal faunas may help to assign what Tobias (1973*a*) calls 'purely relative faunal dates'. This has been the basis of correlations suggested by Maglio (1972) and Cooke & Maglio (1972). Although hominids are considered as part of the total assemblages used in such correlations, the suggestion by Tobias that the hominid material could, or should, be used to derive even a rough age seems to involve a circular argument. The fossil hominids are placed in the untenable (for living hominids) joint role of 'judge' of their own antiquity and 'accused' whose age is subject of investigation.

CONCLUSION

The hominid collections from East and South African localities come from very different palaeoenvironmental settings. The East African area is one of extensive fossiliferous formations, whereas in South Africa one has localized fossil 'sites'. Nevertheless both regions make valuable contributions to hominid studies in different ways.

The South African caves yield large samples of hominids from deposits having a comparatively small vertical thickness. It seems probable that the main hominid-bearing strata within these cave-fills span comparatively short periods of time. The fossils certainly cluster in particular lithological sub-units of the breccias. The fossiliferous strata are frequently separated from the original opening of the cave by deposits, suggesting variable and in some cases possibly long periods, represented by sediments barren of fossils.

In contrast the East African horizons provide only limited numbers of hominids from each locality although these are firmly localized in respect of environment, stratigraphic setting and age of deposition. The South African accumulations are probably the nearest that a palaeontologist studying Plio–Pleistocene hominids approaches to having a large sample from a 'population' spanning only a limited period of time.

The East African hominids are related to a well-established, stratigraphically controlled chronology and yield unique information concerning the time range of possible evolutionary lineages. Conversely the South African cave fills and their contained hominids must still be considered as undated.

Workers in each area need to use evidence from the other if the full potential of both is to be realized. With this in mind, it seems appropriate to close this review by allowing an early hominid representative from each area to express his, or is it her, views on the subject and to have the last word. To obtain the best effect a robust tenor and a gracile soprano should render the following duet to Offenbach's music for 'The Bold Gendarmes'.

AUSTRALOPITHECINE ALLIANCE

We are two primates bold yet wary
Who hide a crest beneath our hair.
To go out hunting we are chary
For we haven't a thing to wear.
Then to our living floor returning
Upon a transient Olduvai shore
    Zinjanthropus and Mrs Ples
    Zinjanthropus and Mrs Ples
We lived together side by side
    Zinjanthropus and Mrs Ples
    Zinjanthropus and Mrs Ples
And were together stratified.

If some days may lack attraction
We build a pile of stones and earth.
When arranged to our satisfaction
We sit and shake with silent mirth.
For they are sure to prove a problem
To archaeologists in years to come.
    Zinjanthropus and Mrs Ples
    Zinjanthropus and Mrs Ples

Although our brains are small in size
Zinjanthropus and Mrs Ples
Zinjanthropus and Mrs Ples
We like to think and theorize.

My maiden name was *transvaalensis*
But love for '*Zinj*' just could not fail.
I linked my neat, meat-modified molars
To that seed & root, nutcracking male.
Despite the distance now between us
No rift or pitfall mars life's whirl
Zinjanthropus and Mrs Ples
Zinjanthropus and Mrs Ples
I'm her robust East African male.
Zinjanthropus and Mrs Ples
Zinjanthropus and Mrs Ples
And I'm his gracile South African girl.

And now the toil and chase are quiet
We both have drawn a last long breath.
After a fierce brief life of riot
Nearly two million years of death.
But if you ask us why we're sleeping
In one enormous Olduvai Bed
Zinjanthropus and Mrs Ples
Zinjanthropus and Mrs Ples
We're linked in death as well as life
Zinjanthropus and Mrs Ples
Zinjanthropus and Mrs Ples
For now we're truly man and wife.

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6. SYSTEMATIC papers must conform with the *International code of zoological nomenclature* (particularly Articles 22 and 51).

Names of new taxa, combinations, synonyms, etc., when used for the first time, must be followed by the appropriate Latin (not English) abbreviation, e.g. gen. nov., sp. nov., comb. nov., syn. nov., etc.

An author's name when cited must follow the name of the taxon without intervening punctuation and not be abbreviated; if the year is added, a comma must separate author's name and year. The author's name (and date, if cited) must be placed in parentheses if a species or subspecies is transferred from its original genus. The name of a subsequent user of a scientific name must be separated from the scientific name by a colon.

Synonymy arrangement should be according to chronology of names, i.e. all published scientific names by which the species previously has been designated are listed in chronological order, with all references to that name following in chronological order, e.g.:

Family Nuculanidae
Nuculana (*Lembulus*) *bicuspidata* (Gould, 1845)
Figs 14–15A

Nucula (*Leda*) *bicuspidata* Gould, 1845: 37.
Leda plicifera A. Adams, 1856: 50.
Laeda bicuspidata Hanley, 1859: 118, pl. 228 (fig. 73). Sowerby, 1871: pl. 2 (figs 8a–b).
Nucula largillierti Philippi, 1861: 87.
Leda bicuspidata: Nicklès, 1950: 163, fig. 301; 1955: 110. Barnard, 1964: 234, figs 8–9

Note punctuation in the above example:
comma separates author's name and year
semicolon separates more than one reference by the same author
full stop separates references by different authors
figures of plates are enclosed in parentheses to distinguish them from text-figures
dash, not comma separates consecutive numbers

Synonymy arrangement according to chronology of bibliographic references, whereby the year is placed in front of each entry, and the synonym repeated in full for each entry, is not acceptable.

In describing new species, one specimen must be designated as the holotype; other specimens mentioned in the original description are to be designated paratypes; additional material not regarded as paratypes should be listed separately. The complete data (registration number, depository, description of specimen, locality, collector, date) of the holotype and paratypes must be recorded, e.g.:

Holotype
SAM–A13535 in the South African Museum, Cape Town. Adult female from mid-tide region, King's Beach, Port Elizabeth (33.51S, 25.39E), collected by A. Smith, 15 January 1973.

Note standard form of writing South African Museum registration numbers, date and geographical positions.

7. SPECIAL HOUSE RULES

Capital initial letters

(a) The Figures, Maps and Tables of the paper when referred to in the text
e.g. '. . . the Figure depicting *C. namacolus* . . .'; '. . . in *C. namacolus*(Fig. 10) . . .'

(b) The prefixes of prefixed surnames in all languages, when used in the text, if not preceded by initials or full names
e.g. Du Toit but A. L. du Toit; Von Huene but F. von Huene

(c) Scientific names, but not their vernacular derivatives
e.g. Therocephalia, but therocephalian

Punctuation should be loose, omitting all not strictly necessary

Reference to the author should be expressed in the third person

Roman numerals should be converted to arabic, except when forming part of the title of a book or article, such as
'Revision of the Crustacea. Part VIII. The Amphipoda.'

Specific name must not stand alone, but be preceded by the generic name or its abbreviation to initial capital letter, provided the same generic name is used consecutively.

Name of new genus or species is not to be included in the title: it should be included in the abstract, counter to Recommendation 23 of the Code, to meet the requirements of Biological Abstracts.

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